Transport Canada
Development

Transports Canada
Développement

TP 6077E

Review of Workload Approach to Stress in Vehicle Operation

Final Report

Prepared for
Transportation
Development Centre

Transport Canada

JANUARY 1985

CA1
DTC 849
85
R28
c.2

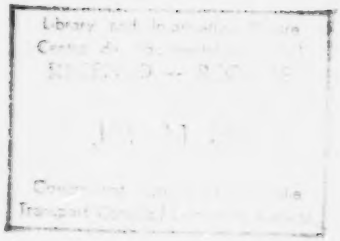
Canada

TP6077E

REVIEW OF WORKLOAD APPROACH TO STRESS IN VEHICLE OPERATION

Prepared for:

Transportation Development Centre
1000 Sherbrooke Street West
Suite 2421
Montreal, Quebec



Project Officer: Dr. R. Heron

Dr. Neville Moray

and

Dr. Alison Smiley

MMS MAN-MACHINE SYSTEMS CONSULTANTS INC.
Toronto, Ontario

1 March 1984

The contents of this report reflect the views of the authors and not necessarily the official views or policies of Transport Canada.

REPORT DOCUMENTATION FORM

1. Transport Canada Report No.	2. TDC Project No.	3. Recipient's Catalogue No.
6077E	6083	

4. Title and Subtitle	5. Report Date
Review of Workload Approach to Stress in Vehicle Operation	January 1985
	6. Performing Organization Report No. MMS .13

7. Author(s)	8. Transport Canada File No.
Neville Moray and Alison Smiley	D1450-146-1

9. Performing Organization Name and Address	10. DSS File No.
MMS Man-Machine Systems Consultants Inc. 118 Baldwin Street Toronto, Ontario	14SD.T8200-3-3544
	11. DSS or Transport Canada Contract No. OSD83-00169

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Transportation Development Centre (TDC) 1000 Sherbrooke Street West Suite 2421, MONTREAL, Quebec	Final - January 1984 - January 1985
	14. Sponsoring Agency Code TDC - 6083

15. Supplementary Notes	16. TDC Project Officer
	Ruth M. Heron

17. Abstract

Studies of operator workload in the context of vehicular control are reviewed. The report concentrates on work since 1979 and on vehicles rather than aircraft, although aerospace studies are included where important new findings of general applicability are available. Work on automobiles, rail transport, maritime transport (including submarines and surface-effect vehicles) is reviewed. Behavioural, physiological and subjective measures and their methods of use are critically assessed. A summary of work prior to 1979 is included. A generic research plan is provided for the study of operator workload in transportation systems. Special problems likely to arise in measuring workload in automated systems are examined. A bibliography of over 200 titles is provided organised by vehicle type and annotated by keywords.

18. Key Words	19. Distribution Statement
Workload, Stress, Aerospace, Automobiles, Trains, Ships, Submarines, Hovercraft, Automation, Physiological Measures, Subjective Measures, Behavioural Measures.	A limited number of copies are available from the sponsorship agency.

20. Security Classification (of this report)	21. Security Classification (of this page)	22. No. of Pages	23. Price
Non-classified	Non-classified	68	Nil

FORMULE DE DOCUMENTATION POUR RAPPORT

1. N° du rapport Transports Canada	2. N° de l'étude — CDT	3. N° de catalogue du destinataire
6077E	6083	

4. Titre et sous-titre	5. Date du rapport
Review of Workload Approach to Stress in Vehicle Operation	janvier 1985
	6. N° du rapport de l'organisme exécutant MMS.13
7. Auteur(s) Neville Moray and Alison Smiley	8. N° de dossier Transports Canada D1450-146-1
9. Nom et adresse de l'organisme exécutant MMS Man-Machine Systems Consultants Inc. 118 Baldwin Street Toronto, Ontario	10. N° de dossier — ASC 14SD.T8200-3-3544
	11. N° de contrat — ASC ou Transports Canada OSD83-00169
12. Nom et adresse de l'organisme parrain Centre de développement des transports (CDT) 1000 ouest rue Sherbrooke Suite 2421 Montréal, Québec H3A 2R3	13. Genre de rapport et période visée Final - janvier 1984 janvier 1985
	14. Code de l'organisme parrain CDT
15. Remarques additionnelles	16. Agent de projet — CDT Ruth M. Heron

17. Résumé

Ce rapport fait le point sur les études concernant la charge de travail des conducteurs de véhicules de transport. Il touche surtout les travaux faits depuis 1979 et les moyens de transport autres que les aéronefs, sans pour autant passer sous silence les résultats d'études aérospatiales susceptibles de trouver une application intéressante dans les transports en général. Les domaines visés sont l'automobile, le transport ferroviaire et les transports maritimes (y compris les sous-marins et les véhicules à effet de sol). Il fait une évaluation critique des moyens et technique de mesure utilisés pour cerner les paramètres psychologiques, physiologiques et subjectifs, ainsi que de l'interprétation des résultats obtenus. Les travaux antérieurs à 1979 font l'objet d'une revue sommaire, après quoi un modèle de plan de recherche est proposé pour l'étude de la charge de travail des conducteurs de matériel de transport. Avant de présenter une bibliographie comportant plus de 200 titres répertoriés selon le type de véhicule visé et accompagnée des descripteurs appropriés, il examine les problèmes particuliers que peut présenter la mesure de la charge de travail des conducteurs de véhicules à pilotage automatisé.

18. Mots-clés	19. Diffusion
Charge de travail, stress, aérospatiale, automobiles, trains, transports maritimes, sous-marins, aéroglisseurs, automatisation, paramètres physiologuqes, paramètres psychologiques, parametres subjectifs.	Le CDT dispose d'un nombre limité d'exemplaires.

20. Classification de sécurité (de ce rapport)	21. Classification de sécurité (de cette page)	22. Nombre de pages	23. Prix
Non-classifié	Non-classifiée	68	-

TABLE OF CONTENTS

FOREWARD	vi
1.0 INTRODUCTION	1
2.0 REVIEWS OF WORKLOAD	4
2.2 Summary of Past Conclusions	4
2.2.2 Methods of Measurement	6
Areas Requiring Research	7
3.0 METHODS OF MEASUREMENT	7
3.1 Physiological Measures	7
3.2 Primary Task Measures	8
3.3 Secondary Tasks	8
3.4 Subjective Rating Scales	9
4.0 VEHICLES	10
4.1 Aerospace	11
4.2 Automobiles	14
4.3 Railway Transport	19
4.4 Maritime Transport	20
5.0 GENERIC RESEARCH PLAN	22
6.0 SUMMARY	24
APPENDIX A : AUTOMATION	
APPENDIX B : BIBLIOGRAPHY	

FOREWARD

This review was prepared to provide the Transport Development Centre, Montreal, with up-to-data information about research on the workload incurred by people driving vehicles. Such information can be used in the design of vehicle control consoles, the estimation of stress, factors likely to induce error, manning levels for safe operation, etc. By far the greatest amount of research has been in the aerospace industry, and several excellent reviews of that work exist covering the period to 1979. This report, therefore, while providing a summary of the earlier work, reviews aerospace studies since 1979, and workload studies both before and after that date on automobiles, marine vehicles, trains, and surface effect vehicles. A special section is devoted to the likely impact of automation in vehicular systems. A discussion of methodology is provided and a generic research plan suitable for studying workload and stress in any type of vehicle is outlined. A bibliography with keywords organized by vehicle type is provided.

Taken as a whole the report should provide the Transport Development Centre with a guide to area in which cost effective investigations can be planned or information found relevant to operator workload in the Canadian transportation environment.

1. INTRODUCTION

Humans have a limited capacity for making decisions and processing information. If that capacity is exceeded they are suffering from excessive workload and undesirable consequences result. These include errors, delays in responding, stress, and if the situation is prolonged, ill health. Efficiency is reduced, productivity suffers, and the likelihood of an accident increases. In the case of vehicular control of all kinds the efficiency with which the environment is scanned and control actions taken is reduced. There may be a variety of secondary effects, such as loss of motivation, reduction in job satisfaction, labour turnover. etc. For the above reasons, it would be desirable to measure how near operators are to the limits of their capacity to control a vehicle efficiently.

The other side of the coin is that prolonged exposure to underload can be equally debilitating. The problem of "vigilance" or "watchkeeping" is a most important one in vehicular control, particularly in long distance driving, long distance railroad journeys, long haul commercial aircraft flights, and wherever automatic control is used. Workload should be measured for the purposes of system design and evaluation, for selection and training, and for setting standards for work. A model or models of workload and stress would allow an analytic prediction of user-machine system performance before the construction of the system and prototype trials.

Weiner (1982) suggests a useful conceptual framework. The properties of the task and the environment in which it is carried out produce "workload" which affects the operator. The latter responds adaptively to the imposed load, trying to maintain "homeostasis" in the face of the disturbance. That is, the operator's physiological state changes and action is taken to offset the "disturbance", where the latter is defined as the demands on the operator's information processing resources. The internal physiological response of the operator is the "strain" imposed by the workload. The existence of strain is not in itself bad or undesirable: indeed it may be required in order for the operator to mobilise sufficient resources to perform the task well (Kahneman, 1973). But if the demands of the imposed load rise sufficiently for the capacity of the operator to be exceeded, then performance will suffer, errors will occur, and the operator will suffer from physiological changes caused by "stress" which, if prolonged, can result in ill-health.

The last ten years have seen several reviews and conferences on the nature of workload. Much of the research has been in the context of military and civilian aerospace operations and concerned with problems of overload rather than underload. Laboratory studies have identified a number of variables relevant to the production and variation of workload, and field studies

have extended these to "real life" situations. Workers such as Gerathewohl (1975) have described workload in a systems design context (See Figure 1), and Jahns (1973) in the context of general vehicular control. The aerospace industry has led the concern with workload in automated systems, because as flight systems become more complex and more highly automated the problem of workload becomes more severe. When workload is predominantly physical, it can be readily measured by traditional means well known in the field of work physiology. In automatic systems however the load is intellectual or cognitive, the problem of measurement is far more severe, and the consequences of overload are harder to predict.

Good quantitative models exist for workload in the manual control of vehicles (Anderson, 1982): the situation with regard to "supervisory" control of systems with autopilots is far less satisfactory.

Despite several reviews, there is still no universally accepted definition of workload (Moray, 1979). It is now generally accepted that it cannot be represented by a single number. However, no accepted vector representation has emerged. A useful definition, which captures the general feeling of many workers is,

> "The cost to the (operator) associated with maintaining acceptable levels of performance may be loosely defined as workload" (Weiner, 1982).

The importance of the problem is seen in a report of the U.S. Coast Guard, who report that:

> "The causes of maritime casualties are seldom technologically sophisticated and obscure. Almost without exception, the proximate or probable causes of collisions, rammings and groundings are well known and widely recognised as some form of human failing. Yet there is little recognition or understanding of the underlying causes of human error. . . . There is an inverse relationship between the known causes of maritime accidents and the areas where research is conducted. Most major maritime casualties are due to some form of human failing, whereas most maritime research resources are expended on hardware." (U.S. Maritime Research Board, 1981).

In the context of system design, Millam (1982) points out that there would be a great cost savings if it were possible to predict whether a vehicle would be beyond the operator's control capacity before prototype construction.

The interaction of workload and the properties of the operator,including factors such as motivation, are also important. It is clear that one way for the operator to avoid stress is to adopt a level of motivation which accepts errors. There is experimental evidence that, as operators become aware

that it is impossible to meet the imposed workload demands, both performance degrades and subjective workload declines, probably because a less than perfect level of performance is accepted by the operator. This effect, which has not been explored in detail, might be named the "comfort/accuracy tradeoff".

Although the vast majority of the research on workload stems from military and civilian aerospace problems, it is important to note that most of the results found in research using one type of vehicle can readily be applied to another type of vehicle. Many of the conclusions about the impact of various variables on information and decision making, about the effects of arousal, the rate of arrival of information, for example, can be generalised to rail and other vehicles, mutatis mutandis, from aircraft studies.

As a result, the heavy emphasis in the bibliography on aerospace data should not be dismissed. The important question is what overall conclusions can be reached which are valid for all systems about workload, its nature and measurement; about research designs; etc. Data and theory in this report should not be ignored because they are catalogued under a type of vehicle in which the reader is not immediately interested.

This report begins with a list of some of the major reviews which have appeared in the last fifteen years. There follows a summary of the main methods for assessing workload levels which are of general application. A brief review of work on each type of vehicle follows, in which are noted the more important papers which apply specifically to one type of vehicle. An outline of a general research paradigm which is vehicle independent is then given. The appendices include a section on automation and a bibliography organised by vehicle type.

The material in this report was obtained from four main sources. The authors have both worked in the field for many years, and have an extensive library of reports, both published and unpublished. A search was made through the standard scientific journals which are the main vehicles for workload research. Information was requested both by mail and phone, and also (during personal visits) from the main workers in the field in North America and Europe. Finally a large scale computer search was carried out, using DIALOG and the SUNY Buffalo Applied Ergonomics data base, and searching psychological, engineering, and general data bases.

While the bibliography does not contain every article in which the term "workload" or "stress" appears, we are confident that no major recent development has been omitted. In preparing the report we have read over 250 papers published since 1979. The vast majority of papers apply well known methods to new situations on a piecemeal basis. A few add substantial, new and important facts or concepts to our understanding of stress and workload, for example the work on individual difference by Hart and her colleagues which will be discussed in Section 3.4.

2.0 REVIEWS OF WORKLOAD

Almost all the major reviews have been in the context of aerospace vehicles. Many of them cover similar ground, and the conclusions reached have much in common. While this is satisfactory, it is less satisfactory that there is no agreed technology guaranteeing an accurate estimate of workload and stress. For reasons noted earlier, all reviews can be considered relevant to all transport systems and types of vehicles.

The most systematic reviews of the field are those by Wierwille and Williges (1980), Wierwille and Williges (1978), Hartman and McKenzie (1979) and Moray (1979). The first is a very large annotated bibliography of most workload literature up to 1979, chosen in the context of, but not limited to aerospace problems. The second is an excellent review of measurement techniques. The third is slanted more towards aerospace and military systems. The fourth is the proceedings of an interdisciplinary conference aimed at clarifying differences in approaches, models, method and terminology between disciplines, drawing on the experience of experimental, mathematical and physiological psychologists, of engineers, and of people from industry. Older reviews include classical papers by Gartner and Murphy (1976), Jahns (1973), several NATO AGARD reports (Hopkins, (1971), Hartman (1975)), and two special issues of Ergonomics (1973,1982).

Since 1979 several review papers have appeared, mainly concerned with methodology and measurement. Among them are Williges and Wierwille (1979), Wierwille (1979), Chiles and Alluisi (1979), and Moray (1982). They cover secondary task methods, physiological methods, subjective measures, and behavioural measures in general. In addition to these papers, which are in the open scientific literature, there are several important publications which are less readily available. These include the massive conference proceedings on workload in pilots edited by Frazier and Crombie (1982), the report on the NASA-Ames program (Hart, 1982), and the two volumes entitled "Workload in Progress" (Metzlerand and Shingledecker, 1982; Shingledecker, 1981), and papers in the Annual University-NASA Joint Conferences on Manual Control. Among the most important recent developments have been studies on individual differences which will be discussed in detail in Section 3.4 of this report. The latter material contains some of the small amount of important innovative work of the last few years. Most of the recent reviews provide useful summaries of old results applied to new settings, rather than work which marks outstanding progress.

2.1 Summary of Past Conclusions.

Although there is no single method for assessing workload and stress, and although as we shall see there is no single

metric for measuring it and no single model for its genesis, there are a number of well established variables which are known to affect load and cause stress. The following list includes most of those which have been found to affect performance, subjective ratings, physiological measures or a combination of them. The sources for this list are not limited to vehicular research.

1. Time pressure -- the less time between events to which the operator must respond the greater the load.

2. Probability of simultaneous demand -- in the limit time pressure gives rise to the need to respond to two inputs or to produce two responses or control actions at the same time. This is the basis of the Time Line Analysis for predicting overload which has been found very successful as a design method in the aerospace industry.

3. Dynamic instability -- if an operator must control a dynamic system such as a vehicle which is unstable in a control theory sense the greater the instability the greater the load.

4. High order of control -- the greater the number of integrations between the control and the system output, the greater the load; the greater the lag between the input to the system and resultant output the greater the load on the operator.

5. Nonhomogeneity of control laws -- if a vehicle must be controlled in two axes (such as pitch and roll), this is not much harder than controlling it in one axis if the control law is the same on each axis. But if the control system transfer function is different on the two axes, for example 1st order in pitch and 2nd order in roll, then a marked increase in load is experienced.

6. High bandwidth -- as the input frequency increases, the operator experiences increasing load, and performance declines as the operator begins to filter out frequencies above about 6 radians per second.

7. High information transmission rates (Information transmission is here measured in bits sec^{-1} as defined by Shannon (1948), where the information content of a set of events is given by

and Pi is the probability of the ith event.

8. Division of attention -- particularly within a single sense modality or response system. This is obviously related closely to the dimension of time pressure, assuming that the operator seldom acts as a parallel processor.

9. Requirement for very precise perceptual judgements or very precise motor control of actions.

10. High noise/signal ratio in the incoming information. This has been the basis of the Optimal Control Theory model of workload (Levison, 1979).

11. Memory load -- the need to retain and process information dynamically in short term memory.

12. Complex intellectual operations -- for example translation or mathematical computation.

13. High payoffs associated with the outcome of action.

14. High risk.

15. Awareness of errors by the operator.

16. Level of arousal.

All the above have been found in one or more studies to cause changes in performance which may be identified with load, or have been judged subjectively by operators to be increasing the load they experience, the stress they feel, or the amount of effort they must put into the task to achieve an acceptable level of performance. Sources are not listed individually because all of them recurr in the literature.

On the other hand, manipulation of one or more of the above does not guarantee a change in workload in all situations regardless of the task and the operator involved. The impact of workload variables is highly task dependent and highly operator dependent. It is certain that workload is multidimensional and no single scalar measure can represent it.

2.1. 2 Methods of Measurement

Table 1 shows a list of the major methods which have been used to measure workload or stress. For excellent reviews of the properties, reliability, and validity of the various methods, see Moray (1979); Hartman and Mackenzie (1979); Wierwille and Williges (1978); Wierwille (1979); Williges and Wierwille (1979); Eggemeier and O'Donnell (1982); O'Donnell (1981); Wierwille and Williges (1980).

Few studies have made use of several measures simultaneously. Where that has been done the results are frequently disturbing, since the correlation between measures which, taken singly, are plausible candidates for workload or stress estimation is very low (Wierwille and Connor, 1983). Our understanding of which measures will reliably correlate is very imperfect, although some ideas are beginning to appear (Wickens and Derrick, 1981). It should be regarded as absolutely

mandatory to use a battery of tests in future research, including performance, physiological and subjective measures, and to perform pilot tests in advance to ensure reliability and sensitivity before data are collected in the main study. The recent data on individual differences (see Section 3.4 to follow) make this even more necessary. An excellent example of workload assessment in an applied setting is the description of the certification of the Airbus 300 (Airbus Industries, 1982).

Areas Requiring Research

At the most general level of application research is required on a unified test battery for use in vehicular research. The battery being developed at USAF Wright-Patterson is not entirely appropriate for field studies of vehicle workload. The battery should include portable physiological, behavioural, and subjective measures, and detailed studies of standardisation and intercorrelation undertaken to ensure validity and reliability.

3.0 METHODS OF MEASUREMENT

The main methods of workload measurement can be classified as physiological, subjective rating scales, primary and secondary tasks. Each technique has been shown to be sensitive to workload under certain circumstances. However in the few experiments where a broad range of measures has been employed correlations between them are often low (e.g. Hicks and Wierwille, 1979). One possible reason for this is that some measures are more sensitive to one aspect of workload than another, for example physiological measures to arousal, subjective rating scales to effort expended, and secondary and primary task measures to task load.

3.1 Physiological Measures

The level of physiological activation can be measured centrally (electroencephalography) or peripherally (heart rate, galvanic skin response, pupil size, catecholamine levels, adrenaline levels). The assumption is made that a high level of physiological activation is associated with a high level of arousal and mental workload. Unfortunately this assumption is not always correct. Emotional state also affects arousal and may be totally unrelated to mental workload. Catecholamine levels increase in anticipation of a stressful event. In the driving literature heart rate has been shown to decrease and galvanic skin response to increase over time irrespective of the driving situation. Also heart rate has been shown to increase in anticipation of starting to drive.

Pupil size appears to be a very reliable measure of workload, the pupil narrowing as workload increases. In many circumstances however, particularly in the field, it is an impractical measure because it is also affected by changing light levels.

Individual differences are a very important feature of physiological measures. Taylor (1975) for example, found galvanic skin response rate to vary 100 fold within a group of subjects. Researchers who have used heart rate note that some subjects have very labile heart rates where response to stress is noticeable whereas others show much less change. Because of these large individual differences it is important that groups being compared should be matched using baseline data, or large subject groups should be used. At least one of these precautions is necessary to ensure group differences are due to the experimental condition being examined and not due to innate group differences. There is some evidence that power spectral analysis can, together with measures of attitudes to the task, greatly reduce the variability of heart rate measures, by emphasizing that part of the heart rate variability which is specifically related to effort.

3.2 Primary Task Measures

Probably the most obvious method of measuring workload is to measure performance on the primary task. Its main advantages over other techniques are its face validity and non-intrusive nature (the behaviour involved is already present). However, it is possible for a subject to show the same performance with two different systems but to expend much more effort on one system than on the other. In many systems it is impossible to derive a satisfactory set of primary task measures, either because it is difficult to decide on what constitutes good performance or because so much of the work is cognitive, such as in fault diagnosis, and cannot be easily measured. If possible, primary task measures should be taken; for the best assessment of workload other measures should also be included. An important development here is in the area of 'embedded tasks' in which the workload index is a naturally occurring aspect of the task.

3.3 Secondary Tasks

Secondary tasks are used to measure the attention demanded by a primary task. In the one-channel model of attention developed by Broadbent (1958) the load imposed on the subject by adding a secondary task can be arranged to exceed his limited capacity so that errors occur. It is assumed that the number of errors made on the secondary task increases as the primary task load increases. Based on Broadbent's theory, a large number of secondary tasks have been developed to measure workload including mental arithmetic, tapping at regular intervals, responding to auditory tones, detecting target digits in a sequence of displayed digits, etc. Some of these tasks were sensitive to workload effects under particular circumstances, but other tasks were not. Brown (1965), for example, found that performance on an auditory, digit detection, secondary task improved with extended driving over a 12 hour period, whereas Riermersma et al (1977) found that performance on a secondary task of reporting odometer changes of 10 km, deteriorated during 8 hours of driving.

The lack of consistency in secondary task results may be due in part to a problem Wierwille and Gutman (1978) have called secondary task intrusion. Using a moving-base simulator and various workload levels they showed that a secondary task, involving reading and repeating random digits from a dash mounted display, did intrude significantly upon the driving task performance at low workload levels, but did not intrude significantly at high workload levels. These results show the necessity of calibrating any secondary task with known workload levels before it can be assumed to be sensitive to a wide range of workload levels.

Another study which sheds light on the inconsistency of secondary task results was carried out by Kramer et al (1981). These authors measured the P300 brain wave elicited by secondary task responses. The P300 has been shown to be elicited by auditory or visual probes that the subjects counts. In one experimental paradigm the primary and secondary task used the same modality, stimulus and stimulus frequency; in another paradigm the primary and secondary task differed in these three dimensions. In the first case an increase in primary task difficulty increased the attention paid, as measured by the amplitude of the P300 wave, to the secondary task probes. In the second case, essentially the opposite was true.

Thus the effects on a secondary task of changing workload will depend on the relationship between the primary and secondary task in terms of the stimulus, stimulus frequency and modality used.

Too often secondary tasks have been selected randomly with no theoretical rationale. It is evident from the above that a secondary task must be calibrated with known workload levels before it can be used to assess unknown levels. As is true with physiological measures, there are large differences between subjects in the sensitivity of the secondary task to changes in the primary task (e.g. MacDonald and Hoffman, 1977). Thus baseline data must be collected on subjects to ensure equivalently sensitive subject groups are being compared.

3.4 Subjective Rating Scales

Subjective rating scales are used to represent the conscious judgement of the performer of the difficulties encountered by him or her in the performance of the evaluated task (Gopher and Braune, 1983). As user-machine systems become more complex and automatic control more sophisticated, the human operator appears to do less and less. However, cognitive workload may remain the same or even increase in such systems. In situations where primary task performance measures are incomplete or non-existent subjective measures of workload are of great importance.

One of the earliest subjective measures of workload developed is the Cooper-Harper rating scale shown in Figure 2.

This scale has been used with experienced pilots to measure the handling characteristics of aircraft. These scales have been shown to be empirically successful but have drawbacks (Moray, 1982). According to the literature they should only be used with very experienced pilots and individual differences, which seem never to have been followed up, might be quite considerable. These individual differences in rating workload have been explored by Gopher and Braune (1983) and Hart (1982). Gopher and Braune used a method of psychophysical scaling and derived a psychophysical function describing the relationship between variations in workload levels and the psychological perception of these changes (as was done for light levels and perceived brightness, for example).

Hart and her coworkers, (Hart, 1982; Hart, Childress and Hauser, 1982; Hauser, Childress and Hart, 1983) at NASA-Ames have reported some very important results on individual differences. Using bipolar rating scales and factor analytic techniques they have found that there are very great differences in what the term "workload" means to different people. There appear to be six main groups of people, who respectively think of workload as time pressure, emotional stress, physical workload, cognitive pressure, performance, emotional stress, task demands, cognitive effort, physical effort, motivation and performance. Hart (1982) also suggests that there several dimensions that combine to create the experience of workload: task-related, subject-related and outcome-related. Each dimension has a number of components as shown in Figure 3. The magnitude and nature of the components may vary for different subjects and the components may or may not co-vary (see Figure 4). The importance given to each component in estimating or reacting to workload also varies (see Figure 5). Thus identical experiences can result in different subjective experiences. As a result different measures may be appropriate for different operators. Figure 6 shows the bipolar rating scale used by Hart to establish the six main meanings of workload. She found that the variance of her estimation was reduced by over 30% when such weightings were included in the analysis.

4.0 VEHICLES

The following sections describe workload research according to mode of transport: aerospace, automobiles, ships and trains. Tables 2 to 5 summarize which workload measurement techniques have been used in each of these. Ratings are shown on a scale of 0 to 2 for up to four dimensions of workload: arousal, task load, effort and difficulty. 0 means no research has been performed in this area using a particular technique, 1 means the value of the technique as a measure has shown mixed results and 2 means the technique has proved useful. The distinction between subjective difficulty and effort has recently become increasingly prominent in the aerospace field due to work sponsored by NASA-Ames. This distinction has yet to be made in the fields of automotive or train research.

4.1 Aerospace

Two large and thorough reviews relevant to workload research and aerospace exist, based on work prior to 1979 (Wierwille and Williges, 1980; Williges and Williges, 1979). They cover both work explicitly performed on aircrew, and also other studies, whether field or laboratory, which might throw light on the problems of workload and stress in the aerospace field. Because of their existence we shall not review earlier work, although a few papers of particular interest will be mentioned where relevant. Their reviews are the natural starting point for anyone interested in vehicular workload of any kind. Several hundred papers are cited. A large amount of research has been done since 1979, but most of it applies well established methods to new problems without adding greatly to our understanding.

In the aerospace industry Time Line Analysis is well established as the major design technique to ensure that crew are not over loaded. This is true to such an extent that analytic models to aid the designer have appeared, such as CAFES and HOS (Parks, 1979; Wherry, 1976; Sundstrom, 1980). Buck, Barany, Lehto, Ings and Payne (1981) review standard industrial techniques derived from time and motion study principles, and believe that such methods can be extended to assess aircrew workload, identify important crew-interface design requirements, and detect task variables relevant to task time and errors. Several of these workers suggest that the analytic models are now adequate for the purpose of cockpit design.

Frazier and Crombie (1982) edited a massive conference proceedings report on methods of identifying pilot workload, again in the context of military aerospace needs. The volume runs to nearly 800 pages. Butterbaugh (1982) discusses the role which artificial intelligence will play in the design of future cockpits for high performance aircraft, particularly in the task of real-time allocation of responsibility between computer and pilot. Butterbaugh, Warner, Lovering and Herron (1981) surveyed "critical incidents" obtained from 573 pilots in the USAF to try to identify the constellation of events which lead to overload and 'near' accidents.

Crombie (1982) describes a "performance cliff" in the context of workload. When a task is very easy performance may decline at first as its difficulty is increased, although it is well within the capacity of the operator. This is because it is so easy that not ehough effort is mobilised. As it becomes harder a domain is reached in which increasing task difficulty is matched by increasing effort by the operator, and performance stays roughly constant. At some point the operator becomes overloaded despite his best efforts, and at that moment there is a catastrophic decline in performance as the operator "falls off the cliff" of performance.

Hart's work explains some of the unreliability reported in the literature, since it implies that the subjective load of a

task, and hence a major component of physiological stress, cannot be defined in terms merely of task variables. The properties of the individual operator must also be considered. Workload appears to be both task specific and operator specific to a considerable extent, and if a task is to be "calibrated" for its workload, it will be important also to consider what group of operators will perform it, and what selection procedure will be appropriate to choose them. That is, operators as well as tasks must be measured when workload or stress is to be predicted. A similar emphasis on individual differences will be found in a discussion of the physiological response to stress by Lindholm, Cheatham and Buckland (1981).

Heffley, Clement and Jewell (1982), and Jex (1982) emphasize non-intrusive primary task measures, which make use of the naturally occurring actions made by the operator in the course of carrying out the task. Their work includes a very interesting approach to modelling behaviour in a control theory sense. They believe that it is possible to identify the transfer functions of systems where the behaviour being modelled is cognitive rather than perceptual motor as in classical control. It should be possible to identify time constants, transfer functions, etc., for goal setting and other more cognitive activities. They discuss the problems of stabilizing a system in terms of cognitive criteria other than, say, root mean square position errors. They also describe the cross-coupled critical stability task which has been developed by Systems Technology Inc., one of the few tasks for measuring spare capacity which has been extensively validated and calibrated in field settings, including road vehicles. Other embedded primary or secondary tasks are described in papers by Shingledecker and Crabtree (1982) and Shingledecker and Cortright (1980). The latter work is part of the attempt at Wright-Patterson Air Force Medical Research Laboratory to develop a mental workload assessment battery which will be sufficiently valid, reliable and sensitive to be used as the basis for a "MILSPEC" to assess all future equipment procured for the USAF. The target date for its implementation is in the mid-1980's.

Jensen (1982) reports that of all the fatal and nonfatal accidents in FAA reports, all but 10% were either decisional, or perceptual motor, almost equally divided. That is, a failure of knowledge as to what procedure to use was very rare.

Rehman, Stein and Rosenberg (1983) found that if subjective ratings could be obtained during a task, rather than after it (as when using the Cooper-Harper scale in its traditional form), the correlation between subjective ratings and performance was substantially increased.

There have been a number of relevant full scale high fidelity simulator studies on workload and pilot error, (Ruffle-Smith (1979), Storm and Merrifield (1980). A useful and thought provoking source of anecdotal information related to workload and error is the NASA publication CALLBACK, in which pilots report

their own experiences on a "no penalty" basis if they are involved in a near accident.

The most favoured measures in aerospace research are the traditional ones of heart rate and heart rate variability, although they still remain unreliable. There is increasing evidence, including unpublished work from Moray's laboratory in Toronto, that power spectral analysis of heart rate variability may be a reliable method , at least in laboratory settings. They have succeeded in extending Mulder's (1979) results to control tasks as well as cognitive tasks, and they have also found that the 0.1 Hz energy of the heart rate variability spectrum depends very closely on the effort invested by the operator rather than simply on the task difficulty. Early in practice the measure showed that the objectively harder conditions were felt, physiologically, to be harder. But later in practice the measure showed that the easier conditions were producing greater physiological effort. Their analysis of subjective ratings and interviews with their operators suggest that the latter had realised that they could not improve their performance on the hard conditions no matter how hard they tried, and were therefore concentrating on trying to do better in the easier conditions. The 0.1 Hz measure reflected this allocation of effort.

A few studies have used eye movements, and here the technology is rapidly improving, both for data gathering and for analysis, (York, Montgomery and Petro, 1982). There are techniques in the process of development which may allow direct real time online measurements of central nervous system activity, such as the P300 and other components of evoked potentials, but at the present time these methods are not of practical use.

In conclusion it should be noted that most aerospace studies are concerned with high levels of workload, particularly in the military setting. The greater problem in long-haul civilian flying however is probably that of under arousal and underload. Little work has been reported on such scenarios in the recent past, at least in field settings.

Areas Requiring Research

A large investment in this area would not be cost effective. The scale of work at NASA and the USAF and Army is such that if information on aerospace problems is required, money should be spent on cooperative research through NASA-Ames. The one possible exception would be on the topic of underload in long haul flights. There may be some special topics of Canadian interest, such as STOL or Arctic operation which should be investigated, but while the NASA programs continue, no significant investment other than for joint cooperation is recommended: Such cooperation should be funded on a "watching brief" basis to ensure transfer of information. Hart's work on individual differences should be extended to other vehicles and other situations.

4.2 Automobiles

While aerospace researchers have concerned themselves primarily with the problems of high workload, automobile researchers have been more interested in low workload situations, such as occur in highway driving. Few studies have examined the effects of high workload situations, such as overtaking or crossing intersections. High workload may become of greater interest in the future when computers in cars allow the presentation of route guidance, engine state etc. information to the driver.

4.2.1 Physiological Measures

A number of physiological measures have been used to examine drivers' workload and arousal. These include heart rate, heart rate variability, galvanic skin response and electroencaphalograms.

The gradual decline in heart rate during extended driving periods is well documented (Harris and Mackie, 1972, Sugarman and Cozad, 1972, Riermersma et al, 1977). Harris and Mackie (1972), in a literature review of fatigue and long distance driving, found that measurements of heart rate were the most effective indicator of number of hours on the road. This decline has been interpreted by most authors as indicating increasing driver fatigue and decreasing alertness. However Riermersma et al (1977) argue that this decline reflects adaptation rather than fatigue because the decline in heart rate is much more pronounced during the first hours of the drive than at the end. This is contrary to the expectation that mental fatigue has a progressive and accelerating effect, and will be more noticeable towards the end of a drive. They also found evidence that anticipation increased heart rate.

Several studies have examined the effects of driving inexperience on heart rate, the idea being that lower workload would be associated with greater experience. In one study inexperienced drivers were found to show greater decreases in heart rate over the experimental period (Lisper et al, 1973), however a second study did not replicate this result (Fagerstrom and Lisper, 1977). O'Hanlon and Kelley (1977) compared poorer and better drivers based on lane drift measurements.

Only a few studies have examined the use of heart rate to assess high workload driving situations. Rutley and Mace (1970) examined heart rate changes at highway on-ramps and off-ramps. Though higher heart rates were found on the roundabouts and on-ramps as opposed to the off-ramps, heart rate changes due to physical workload of shifting gears could not easily be separated from effects due to mental workload. Heyes et al (1976) found higher heart rates in high density compared to low density traffic and, like Riermersma et al (1977) found higher heart rates in anticipation of driving. Helander (1978) studied changes in heart rate before and after overtaking another car. No changes were found, possibly because almost all overtaking

occurred on divided highways where this manoeuvre is not very stressful.

In summary heart rate is affected by anticipation of work and adaptation making it perhaps a better measure of arousal than workload per se.

Heart rate variability has been used to measure stresses such as heat, fatigue due to prolonged driving and inexperience, the idea being that as stress increases, mental effort required to perform the driving task also increases. All the studies found looked at heart rate variability as a measure of a long term continuous stress; no studies were found of temporary stress situations such as overtaking.

O'Hanlon (1972) found that heart rate variability increased markedly with driving time, recovered after rest, dropped substantially after the occurrence of events which realerted the drivers and was little influenced by the frequency of traffic events which affected the driver. Sugarman and Cozad (1972) found a significant negative correlation between heart rate variability and noise level in the car (normal and high ambient noise levels were used). However the presence of a speed controller did not significantly affect heart rate variability. Riermersma et al (1977), in a study of prolonged night driving found heart rate variability to increase over the eight hour period, with a temporary decrease after a fuel stop, and just before the end of the drive. Unlike heart rate, heart rate variability was not affected by anticipation of driving or by adaptation.

Heart rate variability, like heart rate, appears to be a good measure of arousal but not a measure of mental workload. Unlike heart rate, heart rate variability appears to be less sensitive to adaptation and anticipation responses. Little use has been made of derived measures such as the 0.1 Hz component of the heart rate variability spectrum.

Although initial investigations showed some promise in using galvanic skin response to evaluate road design, there has been little research using this measure lately. It has been used successfully to evaluate such road design characteristics as intersection illumination level (Cleveland, 1961), certain expressway design characteristics (Michaels, 1962), radius of horizontal curvature (Murtazin, 1969), roadway delineation painting (Babkov et al, 1974) and road shoulder treatments (O'Hanlon and Kelley, 1974). Also galvanic skin response has been used to evaluate the difficulty of various traffic situations. Hulbert (1957) showed that a high proportion of galvanic skin responses occurred in response to observable traffic events, greater responses being shown to potentially more serious interruptions to the driver's travel. Michaels (1960) showed that the size of response was highest for traffic events with maximum speed difference between another vehicle and the test vehicle. He later observed (Michaels, 1962) that for

freeway driving, the highest responses were obtained when other vehicles merged in front of the subject driver. Helander (1976) examined a wide range of road conditions and found a high positive and significant correlation between galvanic skin response amplitude and brake pressure.

Taylor (1963) in a study of a wide range of traffic and road conditions found that the rate of galvanic skin responses (GSR) did not depend as much on the nature of the road or traffic conditions as they did on the individual subject. Responses occurred at irregular intervals ranging from a few seconds to several minutes, and number of responses was highly correlated with driving experience, the more experienced having fewer responses. A strong tendency was found for GSR rates (here being amplitude/unit time) to increase with time. Like Hulbert (1957), Taylor reported that a high proportion of GSR's were preceded by observable traffic events. Taylor found some significant effects due to road conditions (intersections vs. roads with no crossings) but these were small in size.

In summary, like other physiological measures, galvanic skin response is highly individual in rate and amplitude. However, with careful control of road conditions and design, it has been successfully used as a measure of workload.

Driver's electroencephalograms (EEG) have been studied as indicators of arousal during long distance driving. Lecret et al (1968), Sugarman and Cozad (1972) and O'Hanlon and Kelley (1974,1977) found mean alpha power to increase during long distance driving (4 - 8 hours). Lecret et al (1968) noted a reduction in alpha power at toll booths, while Sugarman and Cozad found a reduction at each destination point during an 8 hour trip. Both alpha and theta power were found to be significantly reduced by the presence of high noise levels within the car. An occurrence of a single emergency event early in the run maintained subjects arousal as indicated by significantly reduced alpha power and better driving performance.

In summary EEG measures have been shown to be good measures of arousal, not surprisingly since they are the most direct physiological measures of cortical activation. Whether or not the EEG would reflect changes in driver workload is a question which does not yet appear to have been addressed. It should be noted that physiological research on animals suggests that high arousal and high information processing are not perfectly correlated.

4.2.2 Secondary Tasks

Three types of secondary tasks have been used by driver behaviour researchers, the first is continuous and designed to measure the spare mental capacity of the driver, the second is intermittent and 'probes' the mental state of the driver by measuring some aspect of behaviour thought to be related to

driving performance, and the third attempts to simulate real-world visual complexity by adding a visual monitoring task to the sparse visual scene usually presented to the subject. The first type of task is aimed at measuring taskload, the second, arousal and while the third is not specifically intended as a measure of taskload or arousal, it does measure some combination of these depending on the experimental setup.

Numerous tasks to measure spare mental capacity have been devised. Brown and Poulton (1961) and Brown (1965, 1966) used an auditory digit detection task to examine workload due to different levels of traffic density, fatigue and inexperience. While the secondary task was performed more poorly in dense traffic and more poorly by drivers failing a licensing exam compared to those passing it, it was performed better after eight hours driving, contrary to expectation. Thus this task was a better measure of taskload than arousal (as much as these two can be distinguished). Another task used by Brown (1967) was the interval production task where the subject repeated as syllable at equally spaced intervals. This task was unaffected when measures were taken several times over a 12 hour driving period.

McDonald and Ellis (1975) used a secondary task where two or three numbers per second were projected onto a hood-mounted display. Subjects repeated as many numbers as possible when the vehicle was stationary and then while vehicles drove around curves of different radii at various speeds. This task successfully showed higher workload for curves of smaller radii taken at higher speeds. MacDonald and Hoffman (1977) used a secondary task employing brief auditory stimuli directed via headphones to the right or left ear requiring a foot pedal response. This task successfully distinguished various levels of workload involved in tracking lanes of different widths.

A probe type of secondary task was developed by Lisper and his colleagues. In this task auditory reaction time is measured on the average once a minute. Auditory reaction time was found to increase during a three hour drive only for the driver, not for a passenger. Tests in a stationary car over a three hour period also showed no change (Laurell and Lisper, 1976). It has also been shown that the arousing effect of listening to the car radio diminished the increase in reaction time. (Fagerstrom and Lisper, 1977). Performance on the auditory reaction time task has been shown to be correlated with some driving performance measures, such as detection of roadside obstacles on a closed track (Laurell and Lisper, 1978) but not with other measures such as detection of highway signs (Lisper, 1966).

4.2.3 Visual Occlusion

A very direct measure of the attention required by a task was made by Senders et al (1967) who used a translucent visor to occlude the view of the driver. When the drivers were allowed less frequent and shorter observations, they tended to drive at lower speeds. Farber and Gallager (1972) used this same

technique to detect the effect of visibility conditions on driving task difficulty on a slalom course. The standard measures of driving performance (manoeuvre smoothness and cones knocked down) were insensitive to task difficulty but attentional demand was sensitive.

4.2.4 Subjective Rating Scales

Very few driving studies have used subjective rating scales to measure driver workload, perhaps because these scales work best in high workload situations and much of the literature concerns itself with the low workload situation found in long distance driving. Allen et al (1977) evaluated driver attitude to different lane markings with an interval rating scale to measure how demanding of the driver's attention lane keeping was. The drivers' ratings showed that discomfort occurred at a visibility level somewhat above the point where lane tracking ability deteriorated. Hicks and Wierwille (1979) in a study using a moving base driving simulator looked at different levels of workload defined in terms of the application point of crosswind gusts in a driving task. Subjective rating scales were sensitive to workload differences while visual occlusion, heart rate variability and secondary task performance yielded no significant workload effect.

4.2.5 Areas Requiring Research

A number of areas should be considered for investigation. First, as the emphasis in the literature shows, there is a need for predicting the underload in car and truck driving which results in falling-asleep accidents and may contribute to a large percentage of alcohol-involved accidents. The U.S. National Highway Traffic Safety Administration is currently developing research plans to investigate inattention-related accidents. The use of 'signature' analysis using a number of workload measures, physiological, primary and secondary task, is being examined as a predictor of on-line underload or under arousal. As was stressed several times in this report, individual differences must be accounted for. Spectral analysis of both steering and heart rate variability may improve the value of these variables in predicting underload.

Overload is also of concern. A Canadian study showed that 55% of personal injury accidents and 30% of fatal accidents are intersection related (Ontario MTC, 1980). Despite this the authors are aware of no studies of driving behaviour at intersections, let alone any study specifically of workload involved in crossing intersections.

Finally, with the development of in-vehicle guidance systems and the greater use of vehicle telephones, an overload situation might be created within the vehicle that should be assessed.

4.3 Railway Transport

Estimates of the percent of railway accidents due to human error vary from 40% (Hagar, 1984) to 75% (Kurz, 1972). Rockwell (1978) reports that in 1976 there were 15,000 train accidents in the United States, 8,000 of these being derailments. Even if only 40% of these are due to human error, the research in the area is shockingly inadequate. As to the nature of the human error, one researcher comments that "although the evidence regarding the precise nature of these deficiencies is unclear, monotony and frequently low task demands together with adverse organismic and workplace conditions suggest that lack of vigilance may be a major underlying factor" (Wilde and Stinson, 1983).

Two studies present evidence that the drowsiness due to the low task demands of train driving results in many unsafe situations. In both studies shift work is shown to exacerbate the problem. Hildebrandt et al (1974) studied the time of day distribution of 2,000 automatically induced emergency braking incidents and of 20,000 failures to respond to respond to a safety device, essentially a 'probe' type of secondary task, which shut down the train if not pressed within 25 seconds. In both cases there were two maxima in the distribution, at 3 A.M. and 3 P.M. The amplitude of the second maxima was correlated with the number of hours worked up to 9 hours. It was concluded that the two maxima resulted from fatigue being superimposed on the normal circadian period. Kogi and Ohta (1975) use near accidents reported by train drivers as their measure of performance. Seventeen percent involved drowsiness or falling asleep. Eighty percent of these incidents took place between midnight and 6 A.M. on the first night of a shift, incidents tended to occur after the engineer had been on duty 8 to 14 hours, but on the second night of a shift problems occurred during the initial two to three hours of duty.

Wilde and Stinson (1983) identified a number of factors involved in engine driving which may make it more difficult to perform a vigilance task. These include hot temperatures, high noise levels, uncomfortable seats and severe disruptions of circadium rhythm because of work-rest schedules that can vary vastly from one day to the next. These authors go on to discuss the devices designed to ensure engine drivers are paying attention to their task. They stress the necessity for the device to orient the driver's attention to the task and for it to be satisfied if indeed the driver is attending. For example, a passive device using a physiological measure not well correlated with attention may not be satisfied even though the driver is attending. According to these authors, most vigilance devices currently available require actions that do not direct the operators attention to the task and can be performed in a semi-automatic fashion. It is clear from the few studies found on workload and train driving that much remains to be done to develop a useful vigilance device.

Another approach to alleviating problems due to low levels of workload was taken by Iiyama (1980) who discusses the use of system ergonomics to optimally distribute train operating functions between humans and machines. Iiyama reports analysis carried out on accidents occurring after some train functions were automated. The results showed that inappropriate allocation of functions lead to excessive expectation of the train's abilities, created dangerous gaps and reduced workers' interest in control of the train.

The Japanese Railway Labour Scientific Research Laboratories (Endo et al, 1980) studied drivers of high speed trains on the shinkansen line. They found evidence of stress in several physiological measures, but these disappeared due to habituation within a few months, and later signs of reduced arousal due to monotony were found even in these very high speed vehicles (The reports form the JRLSRL are in Japanese.)

4.3.1 Future Research

From the railway accident data it is clear that low workload is a major problem. Research needs to be conducted to determine which workload measures correlate best with periods of drowsiness as reported by drivers, and correlate with specific times of day or time on shift that have been shown to be associated with near accidents or accidents. Primary task, secondary task and physiological measures should be considered. It is possible that a combination of 2 or 3 measures may provide the best prediction of low arousal.

From this work, countermeasures of two types could be developed. First, the measures predicting low arousal could be combined with an alerting device or an automatic braking device. Second, the measures could be used to determine the effectiveness of a device of the type now used by some railways, where engineers are required to respond to intermittent signals from the device.

4.4 Maritime Transport

There is little research in the open literature on workload in ships, submarines and surface effect (hovercraft) vehicles. This remains true despite the fact that human error accounts for by far the greater proportion of maritime accidents. (See Lederer, 1981; MacNeill and Cohen, 1976; and the U.S. Coast Guard report cited in the introductory section of this report.) Such studies that refer to workload generally give a different meaning to the term, such as the effect of shift work on inshore pilots (Cooke and Shipley, 1980: Williams, Goldberg and Nieri, 1982; Nieri, 1980; Abernathy, 1980).

Studies of performance and the effect of task variables in ships are almost always concerned with the effect of ships' motion in rough water on performance, and in particular the

conditions under which operators are rendered inefficient by the onset of nausea or vomiting due to motion sickness (kinetosis). Use is commonly made of moving base simulators (e.g. Jex, DiMarco and Clement, 1977) or field studies (e.g. McLeod, Poulton, duRoss and Lewis, 1980). A very wide variety of vessels and operators have been used, as well as a wide variety of laboratory and field tasks, and the reports must be regarded as task and vessel specific. There is not enough information to give a general overview. Generally performance measures are used, and the aim is to correlate performance with motion or with other aspects of life at sea. Little interest in "workload" as such is evident.

Because of the singularly unpleasant experiences associated with kinetosis even when vomiting does not result, all of these studies can be regarded as studies of the effect of physiological stress on operators of maritime vehicles, rather than of workload.

Above Sea State 3 kinetosis is common, and severe kinetosis culminating in vomiting is disabling and severely degrades performance (Malone, 1981; McLeod, Poulton, duRoss and Lewis, 1980; Newman, 1976; O'Hanlon, Miller and Royal, 1977). Large individual differences are found. There is extensive adaptation as a result of exposure to motion, so that many experienced mariners show little or no change in performance in sea states that render the neophyte incapable of functioning. In many cases remarkably slight changes in performance are seen in severe conditions (Wiker and Pepper, 1978). This is particularly true for intellectual (cognitive) activities. Obviously motor activities may be severely affected if the operator is being violently accelerated in a quasi-random fashion. It is an obvious conclusion that the crew station should be designed in such a way is to give the maximum sustained comfortable physical support to the operator. The work station should, for example, be placed low down and amidships where the effects of motion is minimised.

Methodological problems are severe. When large numbers of operators are subjected to severe motion in the range .1 to .3 Hz, and at accelerations typical of sea motion, many become so ill that they either cannot or will not continue with the experiment. The traditional "balanced designs" of psychological experiments are almost never completed. On the other hand, as the experiment continues, many operators will adapt to the motion, after which little effect of motion will be seen, particularly on cognitive tasks of the kind associated with "mental workload". The literature suggests that for well adapted, experienced mariners who are highly motivated, little degradation in performance will be seen below Sea State 4, and above that only if the motion is sufficiently violent to induce severe kinetosis and emesis.

No reference was found on the interaction of "stress", "workload", "motion", and "performance".

Several studies exist of submarines (Human Factors Research Inc., 1965), including a series on the interaction of depth, duration of mission, and rest-work cycles on performance in deep submergence vehicle including emergency escape. The conclusions are that existing mission requirements will not overstress crews, but that more extended missions may require careful planning or work-rest cycles if performance is not to be degraded over long periods. It seems likely that there is a very large amount of data on submarine operator performance in classified military sources, but it does not appear in the standard data bases. Many years ago Kelley (1968) drew attention to the heavy workload involved in controlling submarines due to the high order of control involved in their operation, and proposed predictor displays to reduce the workload. His work on the Ziebolz controller has since come to maturity in a number of systems, including the predictor displays in the latest electronic flight decks of the Airbus 300 and the Boeing 757 and 767. Given the characteristics of submarines, namely that they operate at depths where there is almost no turbulence and wave motion is absent, it seems likely that the most relevant literature is that on vigilance and watch keeping behaviour.

No references were found to research on workload or stress in the operation of surface effect vehicles (hovercraft). The high speeds and characteristic violent vibration of such vehicles suggests that the most relevant literature may well be that of low level helicopter flight.

Finally the reader should look again at the quotations from the U.S. Coast Guard given at the end of the introduction. Workload and human error are intimately related, and the absence of published work in this area is disturbing, especially considering the problems of watch keeping at sea and the number of "radar assisted collisions" which continue to be reported.

Areas Requiring Research

There is room for major research on maritime workload. Such work should not concentrate on the effects of kinetosis. Work should concentrate on low load tasks, such as the study of prolonged watch keeping with and without automatic navigation and steering systems. Research should concentrate on areas in which Coast Guard and other reports show that human errors are particularly common. A preliminary analysis of accident literature should aim to establish a model relating maritime accidents to a model of human information processing.

5.0 GENERIC RESEARCH PLAN

In reviewing the workload literature it has become clear to the authors that less than satisfactory results have been obtained in some of the experimental studies. In this section a generic research plan is outlined which hopefully will avoid some of the pitfalls uncovered.

To assess the workload requirements in any situation it is first necessary to perform a task analysis of the job being performed. Task analysis involves breaking the job down into its component parts, for example, communication, tracking, decision making, monitoring, inspection, etc. Each task component should then be analyzed to define performance measures. These measures might be direct, as in standard deviation of tracking error, or indirect as in near accidents resulting from incorrect decision making. Once primary task measures are established, physiological, subjective and/or secondary task measures can then be determined.

The particular measures which are used are dependent on a number of considerations. The first of these is practicality. Pupil diameter, while an excellent workload measure, is affected by changing ambient light and could only be used where this is constant. Performing a secondary task in a very high workload situation, as in making a left turn in a busy intersection, might be too dangerous.

A second consideration is the workload problem. If low workload is causing difficulties, as in drowsing while driving a train, measures which are in themselves arousing such as a continuous secondary task should be avoided. Measures likely to be sensitive to degrees of low workload should be chosen, such as electroencephalograms and probe type secondary tasks. Conversely, in situations where high workload is of concern, subjective rating scales and continuous secondary tasks would be more sensitive to changes in workload level.

With physiological measures and subjective rating scales, large individual differences exist. Therefore baseline data must be collected on each subject before comparing experimental conditions. Large subject groups are needed to ensure results are valid for a range of the population. Secondary tasks must be tested for sensitivity to changes in workload. Some experimenters have used tasks so simple that they were performed automatically and were unaffected by different experimental conditions. Kramer et al (1981) showed that when a secondary task has a different modality and frequency from the primary task, less attention is paid to it as the primary task becomes more difficult. If, however, the primary and secondary task have the same modality and frequency of response, then more attention is paid to the secondary task as the primary task increases in difficulty. Thus a secondary task of the first type would be appropriate in measuring 'spare mental capacity' but the second type would be more appropriate for measuring level of effort. The effect of the secondary task on performance of the primary task should also be examined. The assumption that performance on the primary task is unaffected must be tested before a secondary task is used experimentally.

Once a workload measure has been selected there are some mathematical considerations. To measure heart rate variability, for example, standard deviation of heart rate, co-efficient of

variation of heart rate or power spectra of heart rate variability may be used. This latter is the most recently developed measure and appears to be more sensitive to workload effects that the other measures. But such measures require very careful planning to take account of how much data is required and at what intervals data should be sampled.

Attention must be paid to time on task, learning and degree of skill, since all of these will affect workload measures. For example, since heart rate declines with time on task, direct comparisons can not be made between driving situations performed early and those performed late in the run. Experience affects workload in that the effort required by a more experienced operator may be less than that for an inexperienced operator, similarly with degree of skill.

Because measures of workload are not equally sensitive in every situation it is prudent to use a number of measures. Correlations between measures should also be examined. One might have less confidence in a secondary task measure which showed no change although large changes in electroencephalogram measures had occurred.

6.0 SUMMARY

A major need is the study of low workload situations in vehicular control. Traditionally this topic has been considered a problem of "vigilance", arousal or fatigue. But it is very doubtful whether the research literature on vigilance is adequate to predict lapses of attention and control in long duration vehicular operation. This should be regarded as a top research priority. It is not the same as research on fatigue.

Second, it is becoming clear that the study of individual differences may be of very great importance in the measurement and prediction of workload effects. Research on this topic should be supported for all vehicles.

Third, research should aim to find a combination of analytic, performance, physiological and subjective measures which, taken together, will give a <u>reliable</u> measurement battery.

Fourth, research is required to develop systems which will monitor the state of arousal of the operator and will prompt him or her at appropriate moments.

Fifth, a major problem is the difference between chronic and transient workload. In many situations low workload or stress may be present for several hours during which occasional bursts of high workload and stress will occur. Few current methods can measure such transients.

Sixth, automation is changing the nature of tasks from

manual to supervisory control. Work is required on the consequences of this change.

Seventh, where possible well standardized measures and apparatus (such as critical tracking task, Cooper-Harper scale, etc.) should be used rather that inventing yet more measures.

Eighth, in all investigations a combination of performance, physiological and subjective measures should be used.

Ninth, studies should be of sufficient duration for transient stress and learning to disappear, unless they are themselves of interest. This argues for several sessions of several hours at least in most investigations. Pre and post task calibration measurements are essential.

APPENDIX A : AUTOMATION

There is a growing interest in the effect of automation on workload and performance in the control of vehicles. As the size and complexity of vehicles and other systems increases, the amount of information processing required of operators has already become too great for efficient and safe performance. As a result designers are turning to automation, and of course automatic pilots have been common for many years both in ships and in aircraft. In recent years the advent of the microprocessor and advances in artificial intelligence even in its primitive forms has not merely unburdened the operator but has radically changed the nature of the task.

The aircraft pilot is now called a "flight manager". There have been a number of serious maritime accidents due to "radar assisted collisions" in which vessels have been allowed to run on automatic pilot without adequate monitoring by the operator in waters which required constant vigilance and accurate navigation. It is clear that with the advent of very precise navigation systems such as LORAN and satellite navigation systems the time is fast approaching when such systems will be coupled directly to the ship's steering and engine controls and the role of the bridge crew will become very much like that of pilots of long range commercial airliners. The task is no longer one of steering and control, but of monitoring automatic systems for faults.

There is no doubt that automatic systems can reduce the workload on operators. The amount of research is still relatively slight, since until recently the required equipment was not widely available for conducting experiments, and the use of real craft or full scale simulators is both expensive and in the case of the former, dangerous.

As vehicles become increasingly complex, automation has replaced the demanding physical tasks of control with different, but also demanding cognitive or intellectual tasks of "supervisory control", a mode of human action which is as yet imperfectly understood.

There is no doubt that the demands of complex vehicles can cause humans to make errors. For example, Ruffle-Smith (1979), using a high fidelity simulator, reported that both in the simulated flight of a Boeing 707 and also in real commercial airline short-haul operations flight crews made errors at a rate of about one every five minutes. (Most of them were self-corrected). It is hoped that automation will reduce such errors, especially those due to cognitive overload.

Aiding by automatic systems may extend from simple power steering in automobiles to the full flight management computers of the Boeing 757 and 767 and the Airbus 300. It may include both elaborate robotic controls (Gneezy, 1979), or simple devices which provide tactile input as a measure of speed or distance in

an automobile, thus relieving vision (Burke, Gibson and Jagacinski, 1980).

An example of a laboratory study of the effect of automation on workload is that by Yoerger (1981). He compared performance and subjective workload ratings in operators "flying" a simulated light aircraft, with different degrees of aid from the automatic pilot. When the task was relatively easy there was little advantage to the automated system, but at high workload levels there was a considerable reduction in load and an improvement in performance. Ephrath (1980) studied the difference in workload between manual and automatic landings.

Foremost among those investigating the effects of automation on workload and performance has been Sheridan (1982) and his co-workers. (See for example, Sofyanos and Sheridan, 1980; Winey, 1981; Gneezy, 1979.) There is no doubt that appropriately designed automatic systems, or, more generally, systems which provide preprocessed information, predictive information, or which perform complex computations at high speeds in such a way as to reduce information processing and decision making, can result in safer and more efficient systems. An obvious example is that of aircraft fitted with autoland capability, which can make it possible for a pilot to land in conditions when poor visibility would make the task impossible under manual control.

On the other hand, warnings have already begun to appear about problems of the interaction of human operators and complex automatic systems. Wiener and Curry (1980), and Boehm-Davis, Curry, Wiener and Harrison (1983) have discussed problems in aircraft automation. And a recent anonymous report (NASA, 1984) underlined the problem of overconfidence in such systems -- a pilot made a "hands off" landing in an aircraft which was not in fact fitted with autoland at the time! One of the authors of the present report was once asked to wait a few minutes while a captain switched on his radar and warmed it up in order that he might be able to see the author's yacht while in mid-Atlantic. The mere installation of automation does not guarantee its effective use, and a system in which workload has been reduced may be more dangerous than the original system.

Even with good systems there are a number of problems. Where the system is under the operator's control the extent to which it is used varies greatly with the degree to which the operator trusts the system, whether he believes that the resulting motion of the vehicle is disturbing to crew or passengers, and the extent to which false alarms are given by warning systems. Operators may develop an inaccurate or unrealistic estimate of the reliability of the system, and may give it too much or too little trust. Training is often difficult. There is experimental evidence that operators find it difficult to learn and maintain skills in operating systems which they only monitor and do not control "hands on" (Schiff, 1983).

Curry and Wiener (op. cit.) give guidelines for the design

of good automated systems, and in a recent workshop on flight automation, the following were judged, by members of the industry, to be the most important questions.

1. What techniques can be developed for testing system integrity and immunity to error?

2. How can decision aiding techniques be used and information transfer improved?

3. How much systems information should be given to the operator and how should it be given?

4. How can monitoring be improved and help the operator to deal with unforeseen situations?

Of these, 3 and 4 are directly related to operator workload, and their appearance among the problems rated most important is an indication that even in the very sophisticated operator-machine community of aerospace industries, the answer is not available currently.

Between automatic vehicles and manually controlled vehicles is the "remotely piloted vehicle". Research on underwater RPVs ahs been extensively carried out in Sheridan's laboratory. (See the earlier references and particularly Sofyanos and Sheridan, 1980.) RPVs may be expected to become increasingly common in a wide variety of environments -- they are the robots of vehicular systems. Two studies by Berry and Rezek (1982) and Rezek (1983) report that controlling such vehicles may be more stressful to operators than flying full size aircraft from the cockpit. They point out that stress levels can greatly exceed those found even in high fidelity moving-base simulators, and that RPVs may cost considerably less. It may well be that RPVs could provide an important technology for exploring high levels of workload and stress in an ethically acceptable way. This deserves further consideration.

Some work on helicopters has appeared, mainly in a military context, and there is a program active at NASA-Ames on measuring workload in helicopter flight, although no results are as yet available. Anderson and Toivanen (1970) found that an autopilot in a helicopter reduced workload, but that heavy "quickening", that is the feed-forward of rate of change information in manual control, was as effective as a full autopilot in reducing position error. Cote, Simmons and Krueger (1982) found that the addition of automatic navigation to a helicopter reduced the load, reduced errors, and reduced the tendency of the navigator to believe that he was flying a correct course with reference to the terrain outside the cockpit when in fact he was lost. The navigators also showed less disturbance due to distractions. Chien, Chen, Ho and Pan (1982) describe an artificial intelligence "expert system" which can help a pilot to identify trends in instrument readings, can aid fault diagnosis, etc. They claim that it can improve control and reduce workload.

Interesting questions are raised by Johannsen and Rouse (1981) who investigated the effect of automation on the amount of long range planning and short range control exercised by pilots. There was little correlation between planning and workload or performance, but automation reduced workload and improved performance. The depth of planning rose with the use of the autopilot, contrary to what the authors expected, probably because it allowed the pilot more time to think, (in this respect the result is similar to the findings of Cote et al just cited). They suggest that there are two kinds of task in vehicular navigation, the one is planning (calling up a plan or "script" to be executed), and the other the actual load involved in carrying out the task. The first is "event driven", the second "time driven". In view of what Hart (1983) has reported about differences in attitudes to workload, it may be expected that different operators will be affected more by one or other of these modes of operation.

It should be noted in conclusion that most automation has been aimed at reducing the workload in high workload situations. In doing so the problem of overload may be solved, but at the price of producing an underload, vigilance problem for the operator. It may be expected also that operators will be less able to deal with unforeseen events in the absence of high levels of manual practice.

Areas Requiring Research

Research is needed on how to design systems and train operators for prolonged periods as monitors of automatic systems. When faults occur and automatic systems fail the underload system is replaced by a situation of very high load. This transition is crucial to the safe operation of vehicles. Research on the response of the operator to such situations should have a high priority.

AEROSPACE

Airbus Industrie, 1982. A300FF Minimum Flight Crew Determination. Airbus Industrie, Toulouse, France.

AEROSPACE, SYSTEM ASSESSMENT, TIME LINE ANALYSIS

Anderson, R.O., 1982. Pilot Models for Flight Control Analysis, in Proceedings, Workshop on Flight Testing to Identify Pilot WLD and Pilot Dynamics (eds. Frazier, M.L. and Crombie, R.B.) AFFTC-TR-82-5, 68-78.

AIRCRAFT, CONTROL THEORY, HUMAN OPERATOR MODELS

Berry, D.T., Rezek, T.W., 1982. A Flight Research Viewpoint. In Proceedings: Workshop on Flight Testing to Identify Pilot WL and Pilot Dynamics, AFFTC-TR-82-5, 207-215.

AIRCRAFT, REMOTELY PILOTED VEHICLES, AUTOMATION, SIMULATORS, STRESS, MOTIVATION

Bowman, J.S., Hagen, J.M., Von Beckh, Harald, 1979. Physiological and Psychomotor Effects of Low Altitude Air Combat Manoeuvering. Naval Air Development Center, Report No.NADC-79283-60.

AIRCRAFT, PHYSIOLOGICAL MEASURES, STRESS, SIMULATION

Brecke, F.H., 1982. Instructional Design for Aircrew Judgement Training. Aviation, Space and Environmental Medicine, 53, 951-957.

AIRCRAFT, MODELS, TIME LINE ANALYSIS, TRAINING

Buck, J.R., Barany, J.W., Lehto, M.L., Ings, D.M., Payne, D.R., 1981. Development of a Methodology for Assessing Aircrew Workloads. Airforce Aerospace Medical Research Lab., AFAMRL-TR-81-50.

AIRCRAFT, SECONDARY TASKS, TIME LINE, SIMULATORS

Butterbaugh, L.C., 1982. Cockpit DesigN for the Future and Challenges to Workload Measurement. In Proceedings of the Workshop on Flight Testing to Identify Pilot Workload and Pilot Dynamics (Frazier and Crombie, Eds.), Edwards AFB, Ca. Jan 19-21, 1982, AFFTC-TR-82-5, AD-A129 333.

AIRCRAFT, AUTOMATION

Butterbaugh, L., Warner, D., Lovering, P., Herron, S., 1981. Pilot Workload: A Survey of Operational Problems. Air Force Wright Aeronautical Labs., Wright-Patterson AFB, Ohio. AFWAL-TR-81-3011.

AIRCRAFT, ERROR, ACCIDENTS, CRITICAL INCIDENTS

Chien, R.T., Chen, D.C., Ho, W.P.C., Pan, Y.C., 1982. Multilevel Semantic Analysis and Problem-Solving in the Flight Domain. National Aeronautics and Space Administration, Washington, D.C. NAS 1.26:169282; T-117, NASA-CR-169282.

AIRCRAFT, AUTOMATION, ARTIFICIAL INTELLIGENCE

Connoly, E.M. and Johnson, P., 1981. An Analytical Model for Developing Objective Measures of Aircrew Proficiency with Multivariate Time Sequenced Data. Performance Measurement Associates, 410 Pine St., Vienna, Va., USA.

AEROSPACE, METHODS, MODELS, MEASUREMENT

Cooke, T.C. and Shipley, P., 1980. Human Factors Studies of the Working Hours of U.K. Ship's Pilots. 1. A Field Study of Fatigue. Applied Ergonomics 11, 85-92.

AEROSPACE, FATIGUE

Crombie, R.B., 1982. Reflections on the Effects of Vehicle Dynamics and Task Difficulty on Cooper-Harper Pilot Opinion Ratings Task Performance and Pilot Workload. In Proceedings of the Workshop on Flight Testing to Identify Pilot Workload and Pilot Dynamics (Frazier and Crombie, eds.) Edwards AFB, Ca.; Jan. 19-21 1982, AD-A129 333, AFF7C-TR-82-5.

AIRCRAFT, TRACKING, SUBJECTIVE RATINGS

Eggemeier, F.T., McGhee, J.Z., and Reid, G.B., 1983. The Effects of Variation in Task Loading on Subjective Workload Rating Scales.

AEROSPACE, SUBJECTIVE MEASUREMENT

Eggemeier, F.T. and O'Donnell, R.D., 1982. A Conceptual Framework for Development of a Workload Assessment Methodology. USAF Aerospace Medical Research Laboratory, Wright-Patterson AFB, Dayton, Ohio.

AEROSPACE, REVIEW, METHODOLOGY, TEST BATTERY

Ephrath, A.R., 1980. Pilot Workload During an Instrument Approach. IEEE Transactions on Systems, Man and Cybernetics, SMC-10, 676-678.

AIRCRAFT AUTOMATION, SECONDARY TASK

Frazier, M.L.and Crombie, R.B., 1982. Proceedings of the Workshop on Flight Testing to Indentify Pilot Workload and Pilot Dynamics Held at Edwards AFB, California on 19-21 January, 1982, AFFTC-TR-82-5.

AIRCRAFT, REVIEW

Gartner, W.B and Murphy, M.R., 1976. Pilot Workload and Fatigue: A Critical Survey of Concepts and Assessment Techniques. NASA-TN-D-8365, A-6630.

AIRCRAFT, REVIEW

Gerathewol, S.J., 1975. Definition and Measurement of Perceptual and Mental Workload in Aircrews and Operators of Air Force Weapons Systems: A Status Report. AGARDOGRAPH, 181.NATO.

AIRCRAFT, MODELS, REVIEW, ERROR, SYSTEMS THEORY

Gopher, D., Braune, R., 1983. On the Psychophysics of Workload: Why Bother with Subjective Measures? Proceedings of the 2nd Annual Aviation Psychology Symposium, April, 1983.

SUBJECTIVE RATINGS

Gulick, R., 1982. Validation of Pilot Workload Estimates Utilizing In-Flight Data. From Proceedings of the Workshop on Flight Testing to Identify Pilot Workload and Pilot Dynamics (Frazier, M.L. and Crombie, R.B., eds.) Edwards AFB, Ca., Jan 19-21, 1982. AFFTC-TR-82-5.

AIRCRAFT, TIME LINE ANALYSIS, ANTHROPOMETRY, COMMUNICATIONS

Harris, R.L., Tole, J.R., Stephens, A.T., and Ephrath, A.R., 1982. Visual Scanning Behaviour and Pilot Workload. Aviation, Space, and Environmental Medicine 53, 1067-1072.

AIRCRAFT, INFORMATION THEORY, EYE MOVEMENTS

Hart, S., 1982. Theoretical Basis for Workload Assessment Research and NASA-AMES Research Center. AFFTC-TR-82-5, 455-470.

AIRCRAFT, SUBJECTIVE MEASURES, INDIVIDUAL DIFFERENCES

Hart, S., 1983. Workload: A Performance Assessment Research Plan. NASA-AMES Workshop.

AIRCRAFT, REVIEWS, METHODS, MODELS

Hart, S., Childress, M., Hauser, J., 1982. Individual Definitions of the Term 'Workload'. In Proceedings of the 8th Psychology in the DOD Symposium.

AIRCRAFT, SUBJECTIVE MEASURES, INDIVIDUAL DIFFERENCES

Hauser, J.R., Childress, M.E., and Hart, S.G., 1982. Rotary Consistency and Component Salience in Subjective Workload Estimation. NASA-University Joint Conference on Manual Control.

AIRCRAFT, INDIVIDUAL DIFFERENCES

Haward, L.R.C., 1975. Emotional Stress and Flying Efficiency, AGARDOGRAPH 181, NATO, Bruxelles.

AIRCRAFT, STRESS, INDIVIDUAL DIFFERENCES

Heffley, P.K., Clement, W.F., and Jewell, W.F., 1982. Overview of Work in Progress on Non-Intensive Assessment of Pilot Workload and Pilot Dynamics. AFFTC-TR-82-5, p. 516-550.

AIRCRAFT, CONTROL THEORY, PRIMARY TASK

Higgins, T.H., 1981. Systems Engineering Evaluation Method for Piloted Aircraft and Other Man-Operated Vehicles and Machines With Hypothetical Example of a Systems Evaluation and Quantified System Performance Workload Rating Scales. Federal Aviation Administration, Washington, D.C. FAA_RD-81-30.

AIRCRAFT, METHODOLOGY, SUBJECTIVE RATINGS

Holley, D.C., Winger, C.M., Deroshia, C.W., Heinold, M.F., Edgar, D.M., 1981. Effects of Circadian Rhythm Phase Alteration on Physiological and Psychological Variables: Implications to Pilot Performance (Including a Partially Annotated Bibliography). NASA-TM-81277; A-8515.

AIRCRAFT, PHYSIOLOGY, CIRCADIAN RHYTHM

Hopkin, V.D., 1970. Human Factors in the Ground Control of Aircraft. AGARD-AG-142-70, NATO, Brussells.

AIRCRAFT

Hwoschinsky, P.V., Neeland, R., and Park, J., 1982. Civil Aviation Performance Enhancement and Error Reduction. AFFTC-TR-82-5, 29-67.

AIRCRAFT, AUTOMATION, SUBJECTIVE RATINGS, PHYSIOLOGICAL MEASURES, SECONDARY TASKS

Jensen, R., 1983. Pilot Performance and Workload Assessment: An Analysis of Pilot Error. NASA-Ames Workshop.

AIRCRAFT, ACCIDENTS, ERRORS

Hinton, D.H., Shaughnessy, J.D., 1978. Adaption of Time Line Analysis Program to Single Pilot Instrument Flight Research. NASA-Langley Research Center, Hampton, Va. NASA-TM-787748.

AIRCRAFT, TIME LINE ANALYSIS, MODELS

Jex, H.R., 1982. Measuring Aircrew Workload: Problems, Progress and Promises. Proceedings of Workshop on Flight Testing to Identify Pilot Workload and Pilot Dynamics (Frazier and Crombie, eds.) AFFTC-TR-82-5.

AIRCRAFT, CONTROL THEORY, METHODOLOGY

Johannsen, G., Rouse, W.B., and Hillman, H., 1981. Studies of Planning Behaviour of Aircraft Pilots in Normal, Abnormal and Emergency Situations. NASA-CR-169319.

AIRCRAFT, AUTOMATION, COGNITIVE BEHAVIOUR

Kantwitz, B.H., 1983. A Theoretical Approach to Measuring Pilot Workload. NASA-Ames Workshop.

REVIEW

Korn, J., Gully, S.W., and Kleinman, D.L., 1983. Validation of an Advanced Cockpit Display Design Methodology via Workload/Monitoring Tradeoff Analysis. Proceedings of the Annual Conference on Manual Control (18th), p. 268-292. AD-A131 256.

AIRCRAFT, MODELS, DISPLAYS

Levison, W.H., 1982. The Optimal Control Model for the Human Operator Theory Validation and Application. AFFTC-TR-82-5, p. 551-579.

AIRCRAFT, OPTIMAL CONTROL THEORY

Linder, G.S., 1961. Effects of Mechanical Vibration on Humans. North American Aviation Inc. NA-59-1420.

REVIEW

Lindholm, E., Cheatham, C., and Buckland, G., 1981. Physiological and Dual Task Assessment of Workload During Training and Simulated Flight. Air Force Office of Scientific Research, Bolling AFB. AFOSR-TR-82-0714.

AIRCRAFT, PHYSIOLOGICAL MEASURES, SECONDARY TASKS

Lindqvist, A. et al, 1983. Heart Rate Variability, Cardiac Mechanics, and Subjectively Evaluated Stress During Simulator Flight. Aviation, Space, and Environmental Medicine 54, 685-690.

AIRCRAFT, SIMULATOR, PHYSIOLOGICAL VARIABLES

Milliam, D.W., 1982. A Pilot's Perspective on Workload in Single Seat Fighters. Proceedings of Workshop on Flight Testing to Identify Pilot Workload and Pilot Dynamics (Frazier and Crombie, eds.) AFFTC-TR-82-5. p. 12-19.

AIRCRAFT, METHODOLOGY

O'Donnell, R.D., 1981. Development of a neurophysiological test battery for workload assessments in the U.S. Air Force. Proc. IEEE Internationaly Conference on Cybernetics and Society, 1981.

AEROSPACE, PHYSIOLOGICAL MEASURES

Ostgaard, M.A., 1982. Automated Aircraft and Flight Control System Design. Proceedings of Workshop on Flight Testing to Identify Pilot Workload and Pilot Dynamics (Frazier and Crombie, eds.) AFFTC-TR-82-5.

AIRCRAFT, CONTROL THEORY, AUTOMATION

Parks, D., 1979. Current Workload Methods and Emerging Challenges. In Moray (ed.) Mental Workload: Theory and Measurement. Plenum. N.Y., 387-416.

REVIEW, TIME LINE ANALYSIS, MODELS, METHODS

Reader, D.C., 1982. Physiological and Performance Parameters or indices of Pilot Workload. Proceedings of Workshop on Flight Testing to Identify Pilot Workload and Pilot Dynamics (Frazier and Crombie, eds.) AFFTC-TR-82-5. p. 322-336.

AEROSPACE, PHYSIOLGICAL MEASURES

Rehmann, J.T., Stein, E.S., Rosenberg, B.L., 1983. Subjective Pilot Workload Assessment. Human Factors 25, 297-301.

AIRCRAFT, SUBJECTIVE RATINGS

Reid, G., Eggemeier, F., Shingledecker, C., 1982. Subjective Workload Assessment Technique (SWAT). Proceedings of Workshop on Flight Testing to Identify Pilot Workload and Pilot Dynamics (Frazier and Crombie, eds.) AFFTC-TR-82-5. p. 281-288.

AIRCRAFT, SUBJECTIVE RATINGS, TEST BATTERIES, METHODS

Reid, G.B., Shingledecker, C.A. and Eggemeier, F.T., 1981. Application of Conjoint Measurement to Workload Scale Development. Proc. Human Factors Society 25th Annual Meeting, 522-526.

AEROSPACE, TEST BATTERY, SUBJECTIVE MEASURES, MEASUREMENT

Reid, G.B., Shingledecker, C.A., Nygren, T.E. and Eggemeier, F.T., 1981. Development of Multidimensional Subjective Measures of Workload. Proc. IEEE. International Conference of Cybernetics and Society, 403-407.

AEROSPACE, METHODOLOGY, MEASUREMENT, SUBJECTIVE MEASURES

Reid, G.B., Eggemeier, F.T. and Nygren, T.E., 1982. An Individual Differences approach to SWAT Scale Development. Proc. 26th Annual Meetings Human Factors Society, 639-642.

AEROSPACE, SUBJECTIVE MEASURES, INDIVIDUAL DIFFERENCES

Repperger, D.W., Rogers, D.B., Van Patton, R.E., Frazier, J., 1982. Study of Task Difficulty with a Subjective Rating Scale. Proceedings of Workshop on Flight Testing to Identify Pilot Workload and Pilot Dynamics (Frazier and Crombie, eds.) AFFTC-TR-82-5.

AIRCRAFT, PERFORMANCE, CONTROL THEORY

Rezek, T.U., 1983. Unmanned Vehicles Systems Experiences at the Dryden Flight Research Facility. NAS 1.15:84913; H-1192; NASA-TM-84913.

AIRCRAFT, AUTOMATION, REMOTELY PILOTED VEHICLES

Roscoe, A., 1982. Heart Rate as an Analytical Means of Pilot Workload. AFF-TC-TR-82-5, 337-349.

AIRCRAFT, CONTROL THEORY, PHYSIOLOGICAL MEASURES, MONITORING

Ruffle-Smith, H.P., 1979. A Simulator Study of the Interaction of Pilot Workload with Errors, Vigilance and Decisions. NASA-TR-78482.

AIRCRAFT, ERROR, SIMULATORS, VIGILANCE

Sharit, J., Salvendy, G., 1982. External and Internal Attentional Environment Reconsideration of the Relationship Between Sinus Arrythmia and Information Load. Ergonomics 25 121-132.

AIRCRAFT, PHYSIOLOGICAL MEASURES, HEART RATE, SPECTRAL ANALYSIS

Schmidt, D.K., 1982. Time Domain Identification of an Optimal Control Pilot Model with Emphasis on the Objective Function. AFFTC-TR-82-5, 580-601.

AIRCRAFT, CONTROL THEORY

Sheridan, T.B., 1983. Proposal to Study the Relationship Between Aircraft Control Automation, Mental Workload and Pilot Error in a Laboratory Simulator. NASA-Ames Workshop.

AIRCRAFT, MODELS, AUTOMATION

Schifflet, S.G., 1980. Evaluation of a Pilot Workload Assessment Device to Test Alternate Display Formats and Control Handling Qualities. Naval Air Test Center, Patuxent River Md. NATC-SY-33R-80.

AIRCRAFT, DISPLAYS

Shingledecker, C., Alton, W.H., and Crabtree, M.S., 1983. Development and Application of a Criterion Task Set for Workload Metric Evaluation. Proc. 1983 SAE Aerospace Congress.

AEROSPACE, TASK BATTERY

Shingledecker, C.A., Crabtree, M.S., Simons, J.C., Courtright, J.F., and O'Donnell, R.D., 1980. Subsidiary Radio Communication Tasks for Workload Assessment in R & D Simulations: I. Task Development and Workload Scaling. AFAMRL-TR-80-126.

AEROSPACE, PERFORMANCE, COMMUNICATIONS, MEASUREMENT

Shingledecker, C.A., Crabtree, M.S., 1982. Subsidiary Radio Communications Tasks for Workload Assessment in R & D Simulations: II. Task Sensitivity Evaluation. Air Force Aerospace Medical Research Lab, Wright-Patterson AFB, Ohio, AFAMRL-TR-82-57.

AIRCRAFT, PRIMARY TASKS

Speyer, J.J., and Fort, A., 1983. Human Factors Approach in Certification Flight Test. Flight Division, Airbus Industrie, Touloure.

AEROSPACE, SYSTEM ASSESSMENT, METHODS, MEASUREMENT

Storm, W.F. and Merrifield, J.T., 1980. Fatigue and Workload in 4-Man C-5A Cockpit Crews (Volant Galaxy). School of Aerospace Medicine, Brooks AFB, Texas, SAM-TR-80-23.

AIRCRAFT, FATIGUE, STRESS

Sundstrom, J.L., 1980. NASA TLA Workload Analysis Support. Volume 1: Detailed Task Scenarios for General Aviation and Metering and Spacing Studies. NASA-CR-3199; D6-32872.

AIRCRAFT, TIME LINE ANALYSIS

Tole, J.R., Stephens, A.T., Harris, R.C., and Ephrath, A.R., 1982. Quantification of Pilot Workload via Instrument Scan. AFFTC-TR-82-5, 234-251.

AIRCRAFT, EYE MOVEMENTS

Tole, J.R., Stephens, A.T., Vivaudou, M., Harris, Jr., R.L., Ephrath, A.R., 1982. Entropy, Instrument Scan and Pilot Workload. IEEE Conference on Systems, Man and Cybernetics, Seattle, Oct. 1982.

AIRCRAFT, EYE MOVEMENTS, MEASURES

Tole, J.R., Vivaudou, M. Harris, Sr., R.L., Ephrath, A., 1982. FMP Study of Pilot Workload Quantification of Workload Via Instrument Scan. NAS 1.26:a169254; NASA CR-169254.

AIRCRAFT, TRAINING, EYE MOVEMENTS

Tole, J.R., Stephens, A.T., Vivaudou, M., Ephrath, A., Young, L.R., 1983. Visual Scanning Behaviour and Pilot Workload. NAS 1,26:3717; NASA-Cr-3717.

AIRCRAFT, EYE MOVEMENTS

Van de Graaf, R.C., 1982. NLR Research on Pilot Dynamics and Workload. Proceedings of Workshop on Flight Testing to Identify Pilot Workload and Pilot Dynamics (Frazier and Crombie, eds.) AFFTC-TR-82-5, 79-90.

AIRCRAFT, CONTROL THEORY, PHYSIOLOGICAL MEASURES

Wasserman, R., Mitchell, J.F., Rickard, W.W., Huber, R.W., Schelhorn, A.E., 1973. In-Flight Simulation of Minimum Longitudinal Stability for Large Delta Wing Transports in Landing Approach and Touchdown. Volume II Supporting Technical Data and Analysis, Calspan-AK-5084-F-1-Vol-2; AFFDL-TR-72-143-Vol-2.

AIRCRAFT, SIMULATORS, SUBJECTIVE RATINGS

Westbrook, C.B., Anderson, R.O., Pietrzak, P.E., 1966. Handling Qualities and Pilot Workload. AFFDL-FDCC-TM-66-5.

AIRCRAFT, SUBJECTIVE MEASURES, PHYSIOLOGICAL MEASURES

Wiener, E.L., Curry, R.E., 1980. Flight Deck Automation: Promises and Problems. Ergonomics 23, 995-1011.

AIRCRAFT, AUTOMATION

Watler, Jr., J.F., Rowell, D.W., Janoski, S.S., Butterbaugh, L,C., 1981. Crew Workload Prediction Study. Air Force Wright Aeronautical Labs, Wright-Patterson AFB, Ohio, AFWAL-TR-81-3140.

AIRCRAFT, MODELLING, TIME LINE ANALYSIS

Wherry, R.J., 1976. The Human Operator Simulator -- HOS. in Sheridan and Johannsen (eds.) Monitoring Behaviour and Supervisory Control. Plenum, N.Y., 283-294.

MODELS, PERFORMANCE, DESIGN

Wierwille, W.W., 1979. Physiological Measures of Aircrew Mental Workload. Human Factors, 21, 575-594.

REVIEW, PHYSIOLOGICAL MEASURES

Wierwille, W.W., Conner, S.A., 1983. Evaluation of 20 Workload Measures Using a Psychomotor Task in a Moving-Base Aircraft Simulator. Human Factors 25, 1-16.

AIRCRAFT, SECONDARY TASKS, PHYSIOLOGICAL MEASURES, PRIMARY TASKS, SUBJECTIVE RATINGS

Wierwille, W.W. and Williges, R., 1978. Survey and Analysis of Operator Workload Assessment Techniques. S-78-101, Systematics, Inc., Blacksburg, VA.

REVIEW, METHODOLOGY, PHYSIOLOGICAL MEASURES, PERFORMANCE, SUBJECTIVE MEASURES, MODELS

Williges, R.C. and Wierwille, W.W., 1979. Behavioural Measures of Aircrew Mental Workload. Human Factors, 21, 549-574.

REVIEW, PERFORMANCE, METHODOLOGY

Yoerger, D., 1979. Man-Machine Performance for a Simulated Aircraft with Multi-level Automatic Control System. Man-machine Systems Laboratory Report, M.I.T.

AUTOMATION, PERFORMANCE, SUBJECTIVE MEASURES

York, R.L., Montgomery, L.D., Petro, J.P., 1982. New Tools for Measuring Aircraft-Pilot Performance, AFFTC-TR-82-5, 396-432.

PHYSIOLOGICAL MEASURES, AIRCRAFT

Aeromedical Aspects of Helicopter Operations in the Tactical Situation, AGARD-CP-24.

HELICOPTERS, AIRCRAFT, WORKLOAD

Anderson, P.A., Toivanen, M.L., 1970. Effects of Varying Levels of Autopilot Performance in the Helicopter Formation Flight Mode. 12543-FR4; JANAIR - 680610.

AIRCRAFT, HELICOPTERS, AUTOMATION, SECONDARY TASK

Bachmann, W. and Udrs, I., (eds.), 1982. Mental Load and Stress in Activity.

REVIEW, PHYSIOLOGICAL MEASURES, STRESS, INDUSTRIAL

Cote, D.O., Simmons, R.R., and Krueger, G.P., 1982. Comparison of Helicopter Copilot Workload While Using 3 Navigation Systems During Nap of the Earth Flight. Army Aeromedical Research Lab, USAARL-82-8.

HELICOPTERS, AIRCRAFT, AUTOMATION, EYE MOVEMENTS, SECONDARY TASK

Gosparian, R.G., 1978. Helicopter Pilot Workload Evaluation. Air Force Instrument Flight Center, Randolph AFB, Texas, USAFIFC-TR-78-2.

AIRCRAFT, HELICOPTERS, PHYSIOLOGICAL MEASURES, SUBJECTIVE MEASURES

Hemingway, J.C., Aiken, G.W., Blaken, C.L., 1982. An Investigation of the Effects of an Isometric Side Stick Controller on Pilot Workload for Helicopter Terrain Flight. AFFTC-TR-82-5, p. 253.

AIRCRAFT, HELICOPTERS, MEMORY, CONTROL THEORY

Phatak, A.V. and Karmali, M.S., 1982. Development of a Pilot Model for Helicopter Mixed Flight Task Segments. AFFTC-TR-82-5, 627-651.

AIRCRAFT, HELICOPTERS, EYE MOVEMENTS, MODELS

Rotendo, G., 1977. Workload and Operational Fatigue in Helicopter Pilots. AGARD-CP-217.

AIRCRAFT, HELICOPTERS, FATIGUE, STRESS

Wewerinke, P., 1977. Performance and Workload Analysis of In-Flight Helicopter Missions. NLR-MP-77013.

AIRCRAFT, HELICOPTERS, OPTIMAL CONTROL THEORY

AUTOMOBILES

Allen, R.W., O'Hanlon, J.F., and McRuer, D.T.,1977. Driver's Visibility Requirements for Roadway Delineation Vol. I Effects of Contrast and Configuration on Driver Performance and Behaviour. Dept. of Transportation, FHWA/RD-77/165, Nov. 1977.

SUBJECTIVE RATING, PRIMARY TASK

Babkov, V.F., Lobanoc, Y.M., Silyanov, V.V., Sitnikov, Y.M., 1974. Efficiency of Various Edge Treatments. Moscow Automobile and Road Research Institute, 1974.

GSR, DELINEATION

Biesta, P.W., Blaauw, G.J., 1976. The Influence of Environmental Factors on Task Load and Driving Behavior. A Preliminary Investigation. Institute of Perception RVO-TNO, Soesterberg, Netherlands. Rept. No. IZF-1976-7; TDCK-67928.

HEART RATE, SECONDARY TASKS, ON ROAD

Brown, I.D., 1965. A Comparison on Two Subsidiary Tasks Used to Measure Fatigue in Car Drivers. Ergonomics, pp. 467-473.

SECONDARY TASK, ON-ROAD, FATIGUE

Brown, I.D., 1966. Subjective and Objective Comparisons of Successful and Unsuccessful Trainee Drivers. Ergonomics.

SECONDARY TASK, SUBJECTIVE RATING, ON-ROAD, EXPERIENCE

Brown, I.D., 1967. Measurement of Control Skills, Vigilance and Performance of a Subsidiary Tasks During 12 Hours of Car Driving. Ergonomics vol. 10, no. 6.

SECONDARY TASK, EXTENDED DRIVING

Brown, I.D., and Poulton, E.C., 1961. Measuring the Spare Mental Capacity of Car Drivers. Ergonomics, 4, 35-40.

SECONDARY TASK, ON-ROAD

Cleveland, D.E., 1961. Driver Tension and Rural Intersection Illumination (Reprint No. 16) Dallas, Texas Transportation Institute.

GSR, ON-ROAD, INTERSECTION ILLUMINATION

Fagerstrom., K.O. and Lisper, H.O., 1977. Effects of Listening to Car Radio, experience and personality of the driver on subsidiary reaction time and heart rate in a long term driving task. In Vigilance Theory, Operational Performance and Physiological Correlates (Mackie, R.R., ed.), Plenum Press, N.Y.

SECONDARY TASK, HEART RATE, EXTENDED DRIVING

Farber, E., Gallagher, V., 1972. Attentional Demand as a Measure of the Influence of Visibility Conditions on Driving Task Difficulty. Highway Research Record, 414, 1-5.

VISUAL OCCLUSION, PRIMARY TASK MEASURES, CLOSED COURSE

Godthelp, H., Milgram, P., Blaauw, G.J., 1983. Driving Under Temporary Visual Occlusion: An Analysis in Terms of the TLC Concept. Paper presented at the 3rd European Annual Conference on Human Decision Making and Manual Control.

VISUAL OCCLUSION, PRIMARY TASK MEASURES, ON-ROAD

Harris, W., Mackie, R.R., 1972. A Study of the Relationshipa Among Fatigue, Hours of Service, and Safety of Operations of Truck and Bus Drivers. Human Factors Research Inc., Tech. Rept. 1727-2, Goleta, Calif.

EXTENDED DRIVING, ON-ROAD, PHYSIOLOGICAL MEASURES, PRIMARY TASK MEASURES

Harris, W., Mackie, R., 1978. A Study of the Relationships Among Fatigue, Hours of Service, and Safety of Operations of Truck and Bus Drivers. Human Factors Research, Inc., Calif.

PHYSIOLOGICAL MEASURES, EXTENDED DRIVING

Helander, M., 1978. Applicability of drivers' electrodermal response to the design of the traffic environment. Journal of Applied Psychology, 1978 Aug. Vol 63(4), 481-488.

PHYSIOLOGICAL MEASURES, ON-ROAD

Heyes, A.D., Armstrong, J.D., Willans, P.R., 1976. A comparison of heart rates during blind mobility and car driving. Ergonomics Vol. 19(4), 489-497.

HEART RATE, ON-ROAD

Hicks, T.G., Wierwille, W.W., 1979. Comparison of five mental workload assessment procedures in a moving-base driving simulator. Human Factors Vol. 21(2), 129-143.

PRIMARY MEASURES, SECONDARY TASK, HEART RATE, SUBJECTIVE RATING, VISUAL OCCLUSION

Hoffman, E.R., MacDonald, W., 1975. Steering reversals as a measure of driver performance and steering task difficulty. Human Factors, 17(3)

PRIMARY TASK MEASURES, TASKLOAD, CLOSED COURSE

Hulbert, S.F., 1957. Drivers' GSR's in traffic, Perceptual Motor Skills, 7, 305-315.

GSR, ON-ROAD

Janssen, W.H., 1983. Driver Task Load in Different Road Environments. Proceedings of 27th Annual Human Factors Society Meeting.

HEART RATE SPECTRUM, P300, CATECHOLOMINE, ON-ROAD

Kelley, C.R., 1963. Self-Adjusting Vehicle Simulators. Dunlap and Associates, Inc., Santa Monica, Calif.

PRIMARY TASK MEASURES, SELF-ADJUSTING CAR SIMULATOR

Kramer,A., Wickens, C., Vanasse, 1., Heffley, E., and Donchin, E., 1981. Primary and Secondary Task Analysis of Step Tracking for Event Related Potentials Approach. Proceedings of the 25th Annual Meeting of the Human Factors Society.

PRIMARY AND SECONDARY TASK, MEASURES, TRACKING, P300

Laurell, H., Lisper, H.- O., 1974. Fatigue in Driving. Paper presented at 1st International Conference on Driver Behaviour, Zurich.

SECONDARY TASK, FATIGUE, REVIEW

Laurell, H., Lisper, H.- O., 1976. Changes in Subsidiary Reaction Time and Heart Rate During Car Driving, Passenger Travel and Stationary. Ergonomics, Vol 19, No. 2.

SECONDARY TASK, HEART RATE., EXTENDED DRIVING

Laurell, H., Lisper, H.- O., 1978. A Validation of Subsidiary Reaction Time Against Detection of Roadside Obstacles During Prolonged Driving. Ergonomics, Vol 21, No 2.

SECONDARY TASK, EXTENDED DRIVING, CLOSED COURSE

Lecret, F., Pin, M.C., Cura, J.B., Pottier, M., 1968. Les Variations de la Vigilance au Cours de la Conduite sur Autoroute. Quoted in Harris, W. and Mackie, R., A Study of the Relationship of Operations of Truck and Bus Drivers. Human Factors Research, Inc., California.

PHYSIOLOGICAL MEASURES, ON-ROAD

Lisper, H.O., Ericksson, B., 1980. Effects of the Length of a Rest Break and Food Intake on Subsidiary Reaction-Time Performance in an 8 Hour Driving Task. Journal of Applied Psychology, Vol. 65, No. 1, 117-122.

SECONDARY TASK, ON-ROAD, EXTENDED DRIVING

Lisper, H.O. Ericksson, B., Fagerstrom, K.O., Lindholm, J., 1979. Diurnal Variation in Subsidiary Reaction Time in a Long Term Driving Task. Accident Analysis and Prevention, Vol. 11, p. 15.

CIRCADIAN RHYTHM, SECONDARY TASK, EXTENDED DRIVING, ON-ROAD

Lisper, H.O., Laurell, Stening, G., 1973. Effects of experience of the driver on heart rate, respiration rate and subsidiary reaction time in a three hour continuous driving task. Ergonomics 16(3), 501-506.

PHYSIOLOGICAL MEASURES, SECONDARY TASK, EXTENDED DRIVING

MacDonald, Hoffman, E.R., 1977. A secondary task measure of driving demands: test track evaluation. Australian Road Research Board Research Report.

HEART RATE, SECONDARY AND PRIMARY TASK, MEASURES, CLOSED COURSE

McDonald, L.B., Ellis, N.C., 1974. Relationship Between Predicted Stress and Measured Attentional Demand in a Simulated Driving Task. Proceedings of the 18th Annual Meeting of the Human Factors Society, p. 117-122.

SECONDARY AND PRIMARY TASK, MEASURES, SIMULATOR

McDonald, L.B., Ellis, N.C., 1975. Driver Workload for Various Turn Radii and Speeds. Presented at the 54th Annual Meeting of the Transportation Research Board, Washington, D.C., Jan. 1975.

SECONDARY TASK, CLOSED COURSE, CURVES

McDonald, L.B., Ellis, N.C., 1975. Stress Threshold for Drivers Under Various Combinations of Discrete and Tracking Workload. Proceedings of the 19th Annual Meeting of the Human Factors Society, Dallas, p. 488-493.

SECONDARY TASK, TRACKING

Mackie, R.R., Miller, J.C., 1978. Effects of Hour of Service Regularity of Schedule and Cargo Loading on Truck and Bus Driver Fatigue. Report of NHSTA, DOT-HS-S-01142, Oct. 1978.

PHYSIOLOGICAL MEASURES, SECONDARY AND PRIMARY MEASURES, REVIEW, ON-ROAD, EXTENDED DRIVING, SUBJECTIVE RATING

Mackie, R.R., O'Hanlon, J.F., 1977. A Study of the Combined Effects of Extended Driving and Heart Stress on Driver Arousal and Performance. In Vigilance Theory, Operational Performance and Physiological Correlates (Mackie, R.R., ed.), Plenum Press, N.Y.

PHYSIOLOGICAL MEASURES, EXTENDED DRIVING, HEART STRESS, ON-ROAD

Michaels, R.M., 1960. Tension Responses of Drivers Generated on Urban Streets. Highway Research Board Bulletin, 271 29-43.

GSR, ON-ROAD

Michaels, R.M., 1962. Effects of Expressway Design on Driver tension responses. Highway Research Board Bulletin, 330, 16-26.

GSR, ON-ROAD

Mulders, H.P., Meijman, T.F., O'Hanlon, J.F., Mulder, G., 1982. Differential psychophysiological reactivity of city bus drivers. Ergonomics Vol. 25(11).

PHYSIOLOGICAL MEASURES, SUBJECTIVE RATING, BUSES

Murtazin, B.S., 1969. The psychological influence of curves during car driving on curving roads. Trydy MADY, rezim, dwizenja automobilej w razlitsnych dotosnyvh uslowiach, 1969, no. 27.

GSR, ON-ROAD

O'Hanlon, J.F., 1972. Heart rate variability: A new index of Driver alertness/fatigue. S.A.E. Paper 720141.

HEART RATE VARIABILITY, PRIMARY TASK MEASURES, ON-ROAD

O'Hanlon, J.F., Kelley, G.R., 1974. A psychophysiological evaluation of devices for preventing lane drift and run-off-road accidents. Human Factors Research, Goleta, Calif., Tech. Rept. 1763-F.

PHYSIOLOGICAL MEASURES, PRIMARY TASK MEASURES

O'Hanlon, J.F., Kelley, G.R., 1977. Comparison of performance and physiological changes between drivers who perform well and poorly during prolonged vehicular operation. In Vigilance Theory, Operational Performance and Physiological Correlates (Mackie, R.R., ed.), Plenum Press, N.Y.

HEART RATE MEASURES, PRIMARY TASK MEASURES, ON-ROAD

Platt, F.N., 1969. Heart Rate Measurements of Drivers with the Highway Systems Research Car. Industrial Medicine and Surgery, Vol. 38, No. 10.

HEART RATE, PRIMARY TASK MEASURES, ON-ROAD

Rabideau, G.F., Maddux, B.J., 1974. Position Paper: Applicability of Driver Fatigue Measurement Techniques to Human Factors Studies of Road Safety. Paper presented at 7th Annual Conference of Human Factors Association of Canada, Ottawa, 1974.

PHYSIOLOGICAL MEASURES, SECONDARY TASK, REVIEW

Riermersma, J.B.J., Sanders, A.F., Wildewanck, C., Gaillard, A.W., 1977. Performance Decrement During Prolonged Night Driving. In Vigilance Theory, Operational Performance and Physiological Correlates (Mackie, R.R., ed.), Plenum Press, N.Y.

PHYSIOLOGICAL MEASURES, SECONDARY AND PRIMARY TASK MEASURES

Riermersma, J.B.J., 1983. The Effects of Stroboscopic Visual Occlusion on Maintaining Course on a Straight Road. Institute for Perception TNO, Soesteberg, Netherlands.

VISUAL OCCLUSION, ON-ROAD

Rule, R.G., Fenton, R.E., 1972. On the effects of state information on driver-vehicle performance in car following. IEEE Trans. Syst. Man Cybern v SMC-2, p. 630-637.

SUBJECTIVE RATINGS, MEASURES, PRIMARY TASK, ON-ROAD

Rutley, K.S., Mace, D.G.W., 1970. Heart Rate as a Measure in Road Layout Design. Road Research Lab., Crowthorne, England, Rep. No. RRL-LR347.

HEART RATE, ON-ROAD

Senders, J.W., Kristofferson, A.B., Levison, W.H., Dietrich, C.W., Ward, J.L., 1967. The Attentional Demand of Automobile Driving. Highway Research Record, 1967, 195, 15-33.

VISUAL OCCLUSION, PRIMARY TASK MEASURES, ON-ROAD

Sugarman, R.C., Cozad, C.P., 1972. Road Tests of Alertness Variables. Calspan Corp., Buffalo, N.Y. Report No. CALSPAN-ZM-5019-B-1; DOT-HS-800 79.

PHYSIOLOGICAL MEASURES, PRIMARY TASK MEASURES, EXTENDED DRIVING

Taylor, D.H., 1963. Drivers' Galvanic Skin Response and the Risk of Accident. Ergonomics, p. 439-451.

GSR, ON-ROAD

Weir, D.H., Allen, R.W., 1972. Physiological and response measurements in driving tasks. SAE Pap 720139 for meeting Jan 10-14 1972.

PHYSIOLOGICAL MEASURES, ON-ROAD

Wierwille, W.W., Gutmann, J.C., 1978. Comparison of Primary and Secondary Task Measures as a Function of SImulated Vehicle Dynamics and Driving Conditions. Human Factors vol. 20 no. 2.

SECONDARY AND PRIMARY TASK MEASURES, SIMULATOR

Wierwille, W.W., Guttmann, J.C., Hicks, T.G., Muto, W.H., 1977. Secondary Task Measurement of Workload as a Function of Simulated Vehicle Dynamics and Driving Conditions. Human Factors Vol. 19(6), 557-565.

SECONDARY TASK, SIMULATOR

Wehterell, A., 1981. Efficacy of Some Auditory-Vocal Subsidiary Tasks as Measures of the Mental Load on Male and Female Drivers. Ergonomics vol. 24(3), p. 197-214.

SECONDARY TASK, ON-ROAD

TRAINS

Endo, T., Fukano, S., Inomata, O., Sugiyama, I., Ikeda, M., Tanizawa, H., 1980. Physiological load of high speed train operation. Japanese National Railways, Railway Labour Scientific Research Laboratory Report (in Japanese)

HEART RATE, HORMONES, STRESS, FLICKER FUSION, INFORMATION PROCESSING, HABITUATION, VIGILANCE

Haga, S., 1984. An experimental study of signal vigilance errors in train driving. Ergonomics 27.

PRIMARY TASK MEASURES, VIGILANCE

Hildebrandt, G., Rohmert, W., Rutenfranz, J., 1974. 12 and 24 Hour rhythms in error frequency of locomotive drivers and the influence of tiredness. International Journal of Chronobiology, 2, 175-180.

SHIFT WORK, CIRCADIAN RHYTHM, SECONDARY TASK

Iiyama, Y., 1980. Systems-ergonomic approaches to design and operation of today's railroads. Human Factors 22, 15-24.

TASK ANALYSIS

Kogi, K., Ohta, T., 1975. Incidence of near accidental drowsing in locomotive driving during a period of rotation. Journal of Human Ergology, 4, 65-76.

SHIFT WORK, NEAR ACCIDENTS

Kurz, F.K., 1972. Identification and categorization of accidents and injuries in cabs of locomotives. Dept. of Transportation, Rep. FRA-OPP-73-3, Washington, D.C., 1972.

ACCIDENT ANALYSIS

Rockwell, T.H., 1978. Human Factors Research Challenges in the

Rail and Underground Coal Mining Industries. Keynote address, 1978 Annual Meeting Human Factors Society, Detroit.

REVIEW

Wilde, G.J.S., Stinson, J.F., 1983. The monitoring of vigilance in locomotive engineers. Accident Analysis and Prevention, Vol. 15, No. 2.

SECONDARY TASK, VIGILANCE DEVICES

SHIPS

Abernathy, C.N., 1980. Computer Simulation of U.S. Coast Guard Watch Stander Performance. U.S. DOT 800447 for Meet. Feb. 25-29, 1980.

SHIPS, SIMULATION, WATCHKEEPING

Cook, T.C., 1982. Stress and Ectopic Beats in Ships Pilots. Journal of Psychosomatic Research 26, 559-569.

SHIPS, STRESS, PHYSIOLOGY

Cooke, T.C., Shipley, P., 1980. Human Factors Studies of the Working Hours of U.K. Ship's Pilots, 1. A field study of fatigue. Applied Ergonomics 11, 85-92.

SHIPS

DiMarco, R.J., Jex, H.R., 1977. Effects of Simulated Ship Motions on Crew Habitability, Phase II Volume 2, Facility Test Conditions, and Schedules. Surface Effect Ships Project Office, Behtesda, Md. PMS-304-TR-1070-Vol-2.

SHIPS, KINETOSIS, SIMULATORS

Gneezy, O., 1979. Microcomputer Based Navigation System for a Remotely Controlled Submersible. Man-Machine Systems Laboratory Report, M.I.T.

SHIPS

Jex, H.R., DiMarco, R.J., Clement, W.F., 1977. Effects of Simulated Surface Effect Ship Motion on Crew Habitability, Phase II Vol. 3, Visual Motor Tasks and Subjective Evaluations. Surface Effect Ships Project Office, Bethesda, Md., PMS-304-TR-1070-Vol-3.

SHIPS, MOTION, INDIVIDUAL DIFFERENCES, CONTROL THEORY

Hall, D.A., Townsend, R.E., Knippa, J., 1979. Stress, Fatigue and Work-Rest Cycles Associated with Deep Submergence Rescue Vehicle Fly-Away Evolution. Naval Health Research Center, San Diego, Ca. NAVHLTHRSCHC-79-16.

SHIPS, SUBMARINES, FATIGUE

Hall, D.A., Townsend, R.E., Knippa, J., Pruett, R., 1980. The Impact of Remote Fly-Away Submersible Operations of Personnel Endurance Capabilities. NAVHLTHRSCHC-79-52.

SHIPS, SUBMARINES, FATIGUE

Hall, D.A., Townsend, R.G., Knippa, J., 1980. Changes in Mood, Fatigue, and Work-Rest Cycles Associated with Deep Submersible Operations. NAVHLTHRSCHC-80-5.

SHIPS, SUBMARINES, FATIGUE

Hall, D.H., Townsend, R.E., Knippa, J., 1980. Changes in Mood, Fatigue, and Work-Rest Cycles Associated with Deep Submersible Operation. NAVHLTHRSCHC-80-5.

SHIPS, SUBMARINES, FATIGUE

Human Factors Research, Inc., 1965. Research on the Development of Shipboard Performance Measures and Performance Judgements. NTIS AD-160489.

SHIPS, METHODOLOGY, INDIVIDUAL DIFFERENCES

Fisher, M.A., 1982. Impact of Motin and Motion Sickness on Human Performance Aboard Monohull Vessels and Surface Effect Ships: A Comparitive Study. Naval Postgraduate School, Montery, Ca. NTIS AD-A124 614/9.

SHIPS, MOTION, KINETOSIS, METHODS

Gunderson, E.K., 1975. Health and Adjustment of Men at Sea. Manual Health Research Center, 75-19. Research Conference on the Social Psychology of Military Service 23-25 Apr. 1975.

SHIPS, SOCIAL FACTORS, INDIVIDUAL DIFFERENCES

Lederer, J., 1981. Research Needs to Reduce Maritime Collisions, Rammings, and Groundings. N00014-75-C-081.

SHIPS, ACCIDENTS

Lindemann, K., 1981. Summary of a Course in Shiphandling in Rough Weather. Coast Guard, Washington, D.C. Office of Merchant Marine Safety. USCG-M-7-81.

SHIPS, MOTION

MacNeill, R., Cohen, S., 1975. Recreational Boat Safety Collision Research -- Phase II Volume II, Collision Accident Investigations 1975. Wyle Labs, Huntsville, Al. MSR-76-39-Vol-2, USCG-D-129-76.

STRESS, SHIPS, ACCIDENTS

Madison, R.L., 1974. Human Factors in Destroyer Operations. Naval Postgraduate School (Masters Thesis) AD-775 011/0.

SHIPS, SOCIAL FACTORS

Malone, W.L., 1981. Effects of Simulated Surface Effect Ship Motions on Crew Habitability, Phase II Volume 2, Summary Report and Comments. Surface Effects Ships Project Office, Bethesda, Md. PMS-304-TR-1070-VOL-1.

SHIPS, SIMULATION, MOTION, STRESS

McLeod, F.D., Poulton, E.C., DuRoss, H., Lewis, W.N., 1980. The Influence of Ship Motion on Manual Control Skills. Defence Research Information Centre, Orpington, England. DRIC-BR-77015, Ergonomics 23, 623-674.

SHIPS, SIMULATOR, MOTION, TRACKING

Miller, J.M., Dykstra, D.R., Gatchell, S.M., 1977. The Visual Behavior of Recreational Boat Operators and its Relationship to Boat Collisions. USCG-D-31-77.

SHIPS, FATIGUE, EYE MOVEMENTS, STRESS

Newman, R.A., 1976. Ship Motion Effects in the Human Factors Design of Ships and Shipboard Equipment. Navy Personnel Research and Development Center, San Diego, Ca. NPRDC-TR-77-2.

SHIPS, MOTION, VISION, DISPLAYS

Nieri, D., 1980. Communications Workload Evaluation of the Proposed Vessel Traffic Service in New York Harbor. National Maritime Research Center, King's Point, N.Y. Computer Aided Operations Research Facility, CAORF-42-7909-01.

SHIPS, SECONDARY TASK, COMMUNICATION

O'Hanlon, J.F., Miller, J.C., Royal, J.W., 1977. Effects of Simulated Surface Effect Ship Motions of Crew Habitability, Phase II, Volume 4, Crew Cognitive Functions, Physiological Stress and Sleep. Human Factors Research, Inc., Coleta, Ca. TR-1757-2; PMS-304-TR-1070-VOL-4.

SHIPS, MOTION, NAUSEA, STRESS

Rubin, R.T., Gunderson, E.K., Arthur, R.J., 1972. Life Stress and Illness Patterns in the US Navy: VI, Environmental, Demographic and Prior Life Change Variables in Relation to Illness Onset in Naval Aviators During a Combat Cruise. Journal of Psychosomatic Medicine 34, 533-547.

SHIPS, STRESS, PSYCHOSOCIAL VARIABLES

Thomas, D.J., Majewski, P.L., Guignard, J.C., Ewing, C.L., 1977. Effects of Simulated Surface Effect Ship Motions on Crew Habitability, Phase II, Volume 5, Clinical Medical Effects on Volunteers. PMS-304-TR-1070-VOL-5.

SHIPS, MOTION, STRESS

U.S. Maritime Research Board, 1981.

SHIPS

Wiker, S.F., Pepper, R.L., 1978. Change in Crew Performance, Physiology, and Affective State due to Motions Aboard a Small Monohull Vessel. A Preliminary Study. USCG-D-85-78.

SHIPS, STRESS, PHYSIOLOGICAL VARIABLES, PERFORMANCE

Wiker, S.F., Pepper, R.L., McCauley, M.E., 1981. A Vessel Class Comparison of Physiological, Affective State and Psychomotor Performance Changes in Men at Sea. USCG-D-07-81.

SHIPS, MOTION, SIMULATOR, METHODOLOGY

Williams, K., Goldberg, J., Nieri, D.S., 1982. Passage Planning: An Objective Assessment of a Bridge Management Procedure versus Integrated Electronic Aids. National Maritime Research Center, Kings Point, N.Y. Computer Aided Operations Research Facility. CAORF-36-8003-01.

SHIPS, DISPLAYS, PLANNING, NAVIGATION

Kelley, C., 1968. Manual and Automatic Control. Wiley, N.Y.

AUTOMATION, CONTROL THEORY, DISPLAYS

AUTOMATION

Schiff, R.B., 1983. An Experimental Study of the Human-Computer Interface in Process Control. MASc Thesis. Department of Industrial Engineering, University of Toronto.

AUTOMATION, DISPLAYS

Sheridan, T.B., Supervisory Control: Problems, Theory, and Experiment for Application to Human Computer Interaction in Undersea Remote Systems. Man-Machine Systems Laboratory, M.I.T.

AUTOMATION, ROBOTICS

Tanaka, K., Buharali, A., Sheridan, T.B., 1983. Mental Workload in Supervisory Control of Automated Aircraft. 20th Annual Joint NASA/University Conference on Manual Control.

AUTOMATION

MISCELLANEOUS (Including General Reviews)

ATC, 1971. An International Symposium on Operator Assessment of Workload in Air Traffic Control Tasks. Ergonomics 14, 545-672.

REVIEW, AIR TRAFFIC CONTROL, WORKLOAD

Barry, P.Z., 1973. The Relationship Between Stress and Accidents: A Preliminary Investigation. Dissertation Abstracts International 34, 743.

STRESS, ACCIDENTS

Boehm-Davis, D.A., Curry, R.E., Wiener, E.L., Harrison, R.L., 1983. Human Factors of Flight Deck Automation: Report on a NASA-Industry Workshop. Ergonomics 26, 953-961.

AIRCRAFT, AUTOMATION, ERROR

Broadbent, D.E., 1958. Perception and Communication. Perganon Press, 1958.

ATTENTION

Burke, W., Gilson, R.D., Jagacinski, R.J., 1980. Multi-Model Information Processing for Visual Workload Relief. Ergonomics 23, 961-976.

AUTOMOBILES, CONTROL, AUTOMATION

Chiles, W.D., Alluisi, E.A., 1979. On the Specification of Operator or Occupational Workload with Performance Measurement Methods. Human Factors, 21, 515-528.

REVIEW, PERFORMANCE, METHODOLOGY

Craig, A., Wilkinson, R.T., Colquhoun, W.P., 1981. Diurnal Variation in Vigilance Efficiency. Ergonomics 24, 641-652.

VIGILANCE, CIRCADIAN FACTORS

Ergonomics, 1973. Journal of the Ergonomics Society. Taylor and Francis, London.

REVIEW (Special Issue on Workload)

Ergonomics, 1982. Journal of the Ergonomics Society. Taylor and Francis, London.

REVIEW (Special Issue)

Fiedler, F.E., Potter, E.H., Zais, M.M., Knowlton, W.A., 1979. Organizational Stress and the Use and Misuse of Managerial Intelligence. Journal of Applied Psychology 64, 635-647.

DECISION MAKING, STRESS, SOCIAL FACTORS

Gerathewol, S.J., 1975. Definition and Measurement of Perceptual and Mental Workload in Aircrews and Operators of Air Force Weapon Systems: A Status Report.

REVIEW, METHODS, SYSTEMS ANALYSIS

Hartman, B.O., 1975. Higher Mental Functioning in Operational Environments. AGARD-CP-181, Brussells.

REVIEW, STRESS, CONTROL THEORY, PERFORMANCE

Hawkins, H.L., Ketchum, R.D., 1980. The Case Against Secondary Task Analyses of Mental Workload. AD-A080 79125.

METHODOLOGY, SECONDARY TASKS

Herbert, A., 1978. Perceived Causes of Difficulty in Work Situations. Ergonomics 21, 539-550.

SUBJECTIVE MEASURES

Hitch, N.M., Brodie, D.A., Harness, J.B., 1980. Cardiac Response to Demanding Mental Tasks. Ergonomics 23.

WORKLOAD, PHYSIOLOGICAL MEASURES, SPECTRAL ANALYSIS

Holley, D.C., Winget, C.A., DeRoshia, C.M., Heinold, M.P., Langton, S.E., Edgar, D.M., Kinney, N.E., Marklet, C.L., Anthony, J.A., 1981. Effects of Circadian Rhythm Phase Alteration on Physiological and Psychological Variables: Implications to Pilot Performance. NASA TM 81227.

CIRCADIAN RHYTHMS, REVIEW

Hyndman, B.W., Gregory, J.R., 1975. Spectral Analysis of Sinus Arrythmia During Mental Loading. Ergonomics 18, 255-270.

HEART RATE, SPECTRAL ANALYSIS

Hyndman, B.W., 1978. Spectral Analysis of the Cardiac Event Sequence Following Mental Loading. Automedica 2, 171-186.

HEART RATE, SPECTRAL ANALYSIS

Jahns, D.W., 1973. A Concept of Operator Workload in Manual Vehicle Operations. Mechenhein Forschung Institut, Fur Anthropotechnik Forschungbericht N. 14.

REVIEW, MODELS, AUTOMOBILE, CONTROL THEORY, TIME LINE

Kahneman, D., 1973. Attention and Effort. Prentice-Hall, Englewood Cliffs, N.J.

REVIEW, ATTENTION, MODEL, EFFORT

Kennedy, R.S., 1975. Some Practical Considerations for Performance Testing In Exotic Environments. AGARDOGRAPH 181, NATO.

AIRCRAFT, MEASURES, VIGILANCE, AROUSAL

Knight, J.L., Geddes, L.A., Salvendy, G., 1980. Continuous, Unobtrusive Performance of Physiological Monitoring of Industrial Workers. Ergonomics 23, 501-506.

METHODOLOGY

Knight, J.L., Salvendy, G., 1981. Effects of Task Feedback and Stringency of External Pacing on Mental Load and Work Performances. Ergonomics 24, 757-764.

METHODOLOGY, FEEDBACK

Konz, S., 1979. Work Design. Grid, Columbus, Ohio.

WORK, WORKLOAD

Lacey, J.I., 1967. Somatic Response Patterns and Stress: Some Revisions of Activation Theory. In Psychological Stress: Issues in Research, Appleby, M.H. and Trambull, R. (eds.) Appleton Century, N.Y., pp. 14-42.

AROUSAL, STRESS

Levison, W.H., 1979. A model for Mental Workload in Tasks Requiring Continuous Information. In Moray, N. (ed.), Mental Workload: Theoryi and Measurement. Plenum, N.Y., 189-218.

REVIEW, METHODOLOGY, OPTIMAL CONTROL THEORY

Moray, N., 1979. Mental Workload: Theory and Measurement. Plenum Press, N.Y.

REVIEW, METHODS, PERFORMANCE, SUBJECTIVE MEASURES, PHYSIOLOGICAL MEASURES

Moray, N., 1982. Subjective Mental Workload. Human Factors, 24, 25-40.

SUBJECTIVE MEASURES

Mulder, G., 1979. Mental Load, Mental Effort and Attention. In Moray (ed.) Mental Workload: Theory and Measurement, Plenum, N.Y., 299-326.

Ogden, G.D., Levine, J.M., Eisner, E., 1979. Measurement of Workload by Secondary Tasks. Human Factors, 21, 591-598.

REVIEW, SECONDARY TASKS, METHODOLOGY

Oswald, I., 1962. Sleeping and Waking, Ebevier, Amsterdam.

REVIEW, SLEEP, STRESS, PHYSIOLOGY

Parasuraman, R., 1984. Sustained Attention in Detection and Discrimination. In Parasuraman, R. (ed.), Varieties of Attention. Academic Press, N.Y., 243-272.

VIGILANCE

Payne, P.R., 1980. On Quantizing Ride Comfort and Allowable Accelerations. N00167-76-M-839. Payne, Inc., Annapolis, Md.

METHODS, CONTROL THEORY, MEASURES

Potter, E.H., Fiedler, F.G., 1981. The Utilization of Staff Member Intelligence and Experience Under High and Low Stress. Academy of Management Journal 24, 361-376.

STRESS, INTELLIGENCE, SOCIAL FACTORS

Poulton, E.C., 1978. Blue Workload Stressors. Stress at Work: Cooper, C.L. , Payne, R., Wiley.

STRESS, INDUSTRIAL TASKS

Richardson, J., Fiorisavary, N., Xirau, D., 1982. The Use of Operator Workload Measures in the Evaluation of Different Tele-Manipulators. Ergonomics 25 p. 553-553.

AUTOMATION, METHODOLOGY

Rompleman, o., Van Kampen, W.H.A., Backer, E., Offenhaus, R.E., 1980. Heart Rate Variability in Relation to Psychological Factors. Ergonomics 23, 1101-1116.

HEART RATE, SPECTRAL ANALYSIS, INDIVIDUAL DIFFERENCES

Sarasan, I.G., Potter III, E.H., 1983. Self Monitoring Cognitive Process and Performance. Dept. of Psychology, Washington University, Seattle. N00014-80-C-0522.

STRESS, INDUSTRY, SOCIAL FACTORS, INDIVIDUAL DIFFERENCES

Salvendy, G., Stewart, G.K., 1975. The Prediction of Operator Performance on the Basis of Performance Tests and Biological Measures. American Institute of Industrial Engineers Transactions 7, 379-387.

PHYSIOLOGICAL MEASURES, INDUSTRIAL TASKS

Shannon, C., 1948. The Mathematical Theory of Communication. University of Illinois Press, Urbana, Illinois.

MODEL

Sharit, J., Salvendy, G., 1982. External and Internal Attentional Environments: II, Reconsideration of the Relationship Between Sinus Arrythmia and Information Load. Ergonomics 25, 121-132.

HEART RATE, POWER SPECTRAL ANALYSIS, INDIVIDUAL DIFFERENCES

Sharit, J., Salvendy, G., 1982. Organizational Stress: Review and Reappraisal. Human Factors 24, 129-162.

INDUSTRIAL TASKS, PHYSIOLOGICAL MEASURES, STRESS, AROUSAL

Sharit, J., Salvendy, G., Deisenroth, M.P., 1982. External and Internal Attentional Environments: I, The Utilization of Cardiac Decelatory and Accelatory Response Data for Evaluating Differences in Mental Workload Between Machine-Paced and Self-Paced Work. Ergonomics 25, 107-120.

HEART RATE, INDUSTRIAL TASKS, TIME STRESS

Shingledecker, C., 1981. Register of Research in Progress on Mental Workload.

REVIEW

Sinus Arrythmia, 1973. Symposium on Heart Rate Variability. Ergonomics 16, 1-112.

REVIEW, PHYSIOLOGICAL MEASURES, CARDIAC VARIABLES, SPECTRAL ANALYSIS

Soulsby, E.P., 1982. Human Operator Workload: A Survey of Concepts and Assessment Techniques. TR-EECS-82-4. Dept. of Electrical Engineering and Computer Science, University of Connecticutt, Storrs, Conn. 06268.

REVIEW

Storm, W.F., McNee, R.C., Albanese, R.A., Hartman, B., 1975. The Effect of 2 Stressors on Traditional and Engineering Analogues of Cognitive Functioning. AGARDOGRAPH 181, NATO, Brussells.

SHIPS, STRESS, PERFORMANCE, COGNITIVE TASK

Weiner, J.S., 1982. The Measurement of Human Workload. Ergonomics 25, 953-965.

REVIEW, STRESS, STRAIN, LOAD

Wierwille, W.W., Williges, B.H., 1980. An Annotated Bibliography on Operator Mental Workload Assessment. SY-27R-80 Naval Air Test Center, Patuxent River, Md.

REVIEW

Winey, C.M., 1981. Computer Simulated Visual and Tactile Feedback as an Aid to Manipulator or Vehicle Control. Man Machine Systems Lab., M.I.T.

SIMULATOR

Wolf, J.D., 1978. Crew Workload Assessment Development of a Measure of Operator Workload. Air Force Flight Dynamics Lab., Wright-Patterson AFB, Ohio. AFFDL-TR-78-165.

AEROSPACE, METHODOLOGY, TEST BATTERY